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24 July 1980

USSR Report

ENERGY

(FOUO 12/80)

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USSR REPORT

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ELECTRIC POWER

WORKERS ADOPT SOCIALIST COMMITMENTS ON POWER PROJECTS

Moscow GIDROTEKHNICHESKOYE STROITEL'STVO in Russian No 5, May 80 pp 1-5

/Article: "Socialist Commitments of Personnel of Labor Enterprises and Organizations of the USSR Ministry of Power and Electrification for 1980"/

/Text/ The staffs of labor enterprises and organizations of the USSR Ministry of Power and Electrification are steadfastly implementing the resolutions of the 25th Congress of the CPSU on further cultivation of the country's power potential. Having developed socialist competition for fulfillment of the 1979 quotas, they have provided the national economy with electric and thermal power within the specified plan. A total of 1147.2 billion kilowatt-hours of electric power and 839.3 million gram-calories of thermal power were generated. The yield of industrial production amounted to 20.1 billion rubles including 145.9 million rubles above the plan.

In electric power plants of the Ministry 10.9 million kilowatts of new power capability were activated. The Nurekskaya GES /hydroelectric power plant/ (with 2.7 million kilowatts) and the Iriklinskaya GRES /State regional electric power plant/ (with 2.4 million kilowatts) produced at full planned capacity and turbines were put into operation at the Kurekskaya, Chernobyl'skaya and Armyanskaya atomic power plants along with the second and third 640,000 kilowatt hydraulic turbogenerator units at the Sayano-Shushenskaya GES and others. High-power electric power transmission lines were constructed including ones from Vinitsa to Al'bertirsha and from the Kurskaya atomic power plant to Bryansk.

Second phase generating equipment was put into operation at the Volgodonskiy Atommash for producing atomic power plant machinery at one million kilowatts per year. The first machinery for the Nadezhdinskiy metallurgical plant has been manufactured by the Tol'yattinskiy plant of the Kuybyshevazot association and so on. General Secretary of the CPSU Central Committee and Chairman of the Presidium of the USSR Supreme Soviet comrade L. I. Brezhnev gave a high rating to the labor of the leading crews in his greetings to the builders, installers and operators of the Nurekskaya GES, the Iriklinskaya GRES and the Armyanskaya atomic power plant, the Orenburgskiy gas plant and the Vinnitsa to Albertirsa 750 kilovolt electric power transmission line and to the power engineers of the Kostromskaya GRES. These greetings resulted in a new influx of creative effort in all the personnel of the sector.

Responding with actual deeds to the resolution of the November (2979) Plenum of the CPSU Central Committee and guided by assumptions and conclusions presented in the speeches at the Plenum by General Secretary of the CPSU Central Committee and Chairman of the USSR Supreme Soviet comrade L. I. Brezhnev, power engineers and power builders have widely developed socialist competition for a worthy celebration of the 110th anniversary of the birth of V. I. Lenin and for the successful completion of the 1980 plan and the 10th Five-Year Plan as a whole and have resolved to work under the slogan "We will build ahead of schedule and finish ahead of schedule."

Operating, construction and installation crews of the Kostromskaya and Reftinskaya GRES's and the Chernobyl'skaya and Kol'skaya AES's /atomic power plants/ have come forward with patriotic initiative in developing socialist competition in the sector and have undertaken intensive counter plans and commitments for the ahead-of-schedule incorporation and completion of machinery, conservation of fuel and energy resources and improvement of technical and economic indicators.

Following their patriotic example, the work crews of the power engineering sector have resolved to turn 1980 into a year of intense Lenin work. They have undertaken the following commitments for the 110th anniversary of V. I. Lenin's birth:

to economize by reducing the relative consumption of conventional fuel by at least 600,000 tons compared with the corresponding period of last year;

to implement a four-month program to produce a return amounting to 6 billion rubles; to obtain 10 million rubles in above-plan profits;

to put new power engineering and generating equipment into operation ahead of schedule, including: 103,000 kilowatt hydraulic turbogenerator No 7 in Dneproges-2; 78,000 kilowatt hydraulic turbogenerator No 3 in the Nizhnekamskaya GES; a 110 kilovolt overhead line from Turki to NS-6 in Saratovskaya oblast; a 220 kilovolt overhead line from Nizhneangarsk to Muyakan on the Baykal-Amur Mainline and the main pumping station of the Zhigylevskaya irrigation system;

to develop:

a). an engineering draft for the first power system in the country, Yuzhno-Ukrainskiy, consisting of hydraulic, pumped-storage and atomic power plants which will make it possible to obtain an economic return on the order of 40 million rubles;

b). comprehensive target programs for developing experimental and industrial solar and geothermal power plants.

In 1980 power engineers and electric power builders will undertake the following socialist commitments.

In the Area of Electric Power Plant and Network Operation

To focus basic attention on providing a reliable and continuous supply of electric and thermal power for the national economy and the country's population based on a further increase in the reliability and efficiency of equipment operation in electric power plants and networks, better use of power generating machinery, a reduction in the time for developing new equipment, intensified conservation of fuel and energy resources, broad dissemination of the experience of leading crews, intensification of the action of the economy on increasing the efficiency and quality of work in all phases of power production.

To fulfill the plan for capital maintenance of basic power equipment and preparation of electric power plants and networks for operation in the fall and winter of 1980-1981 in accordance with the approved schedule and with excellent and top-quality ratings. To manufacture spare parts for power equipment by 600,000 rubles above the plan.

To reduce the idle time of equipment under repair by 0.5 percent of that outlined in the plan which will make it possible to reduce the idle time of power units under capital maintenance by 30 days and to obtain an additional 129 million kilowatt-hours of electric power and save 780,000 rubles.

To obtain an increase in the use of 500,000 and 800,000 kilowatt power unit capacity of at least 1.5 percent compared with the level achieved in 1979 which will provide an additional electric power output of around one billion kilowatt-hours.

To obtain at least 25 million rubles of above-plan profits by increasing the efficiency of power generation and lowering the net cost of electric and thermal power.

To put into practice measures to automate and mechanize the production of electric and thermal power, increase the level of standardization, adopt scientific labor organization and, as a result, conditionally release 6,000 industrial and production personnel.

To implement by 22 December measures to eliminate the gap between rated and available power which will make it possible to increase the total effective power by 2.4 million kilowatts and to generate at least 3 billion additional kilowatt-hours of electric power.

To convert labor organization to collective systems (team method) in maintenance work involving at least 40 percent of workers in production and maintenance enterprises of operating main administrations and Glavenergoremont /Main Administration for Power System Maintenance/.

To achieve a 0.2 hour reduction in the idle time of railroad cars at electric power plants compared with the norm which will make it possible to release more than 4,000 cars per year.

In the Area of Capital Construction

To focus the efforts of builders and installers of organizations on accomplishing the fulfillment of quotas for the first year of the five-year plan in the area of capital construction. To direct the activity of builders and installers to increasing production efficiency and the quality of building and installation work, economizing on building materials, reducing the duration of construction work and the number of incomplete projects, the loss of work time and the idle time of machines and equipment. To organize the broad introduction of collective systems of labor organization, team contract, the initiative of the Rostovskoye enterprises "To work without lagging behind" and also competition under the slogan "Working relay race".

To insure the fulfillment of the government plan on capital investment in the amount of 5.6 billion rubles including 4.2 billion rubles in the electric power engineering sector.

To incorporate 17,623 kilowatts of power capacity in construction projects by the end of the year, of them 4,070,000 kilowatts ahead of schedule, 34,700 kilometers of electric power transmission line with 35 kilovolts of power and more.

To put into operation three months before the specified deadline the next hydraulic turbogenerator unit at the Zeyskaya GES, hydraulic turbogenerator No 4 with 640,000 kilowatt capacity at the Sayano-Shushenskaya GES and to manufacture hydraulic turbogenerator No 5 with 640,000 kilowatt capacity for the Sayano-Shushenskaya GES by Power Engineering Day--the 60th anniversary of the GOELRO [State Commission for the Electrification of Russia] Plan,

To fulfill the contract commitment on incorporating power equipment into foreign projects.

To increase labor productivity in construction by 4.3 percent, 0.1 percent higher than the plan quota, on the basis of adopting the advanced production experience of the Sevzapenergomontazh and Kavkazelektroset'stroy trusts and the construction administration of the Reftinskaya GRES.

To accomplish at least 30 percent of the annual work volume (2 billion rubles worth) by the team contract method.

To continue work on introducing the piece-work wage payment system and attain coverage of at least 70 percent of piece workers with it.

To economize in the comsumption of the following basic construction materials above the specified norm: 8.200 tons of metal, 23,000 tons of concrete and 9,800 cubic meters of lumber.

To incorporate 32 test prototypes of new construction equipment, machinery, production lines and automation facilities for construction and installation work, at least 1,120 standardized sets of manual and automatic devices for plastering, painting, roofing and other work which will make it possible to reduce the amount of work done by hand by 2 percent above the specified quota.

To lower unproductive loss of builder work time by 10 percent compared with 1979 and to lower machinery and equipment idle time by 16 percent.

To achieve a reduction in rail car idle time of 0.1 hour above the norm.

In the Area of Industrial Product Fabrication in Enterprises of the Industrial Construction Industry

To implement ahead of schedule by 29 December the yearly plan on the volume of product fabrication and production of a large number of very important types of items. To produce by the end of the year an additional 5 million rubles worth of products. To obtain the entire increase in product output by increasing labor productivity.

To overfulfill the plan on the production of commodities for national consumption by 500,000 rubles worth.

To achieve a volume of manufactured products for machine-building with the emblem of quality for up to 8.2 percent of the total volume and to increase it by 2.5 percent compared with the five-year plan quotas.

To manufacture 6 million rubles worth of above-plan products of the highest quality for the machine-building sector and 9 million rubles worth of above-plan products for the industrial construction materials sector.

To certify 32 types of items with the state emblem.

In the Area of Scientific Research, Design and Exploratory Planning Work

To focus the attention of personnel of scientific research and planning and design institutes of the power engineering sector on further increasing the efficiency and quality of scientific and design developments, accelerating the incorporation of the achievements of scientific and engineering progress in power engineering and construction production, creating new sources of electric power, industrializing power construction through accelerated development of atomic power engineering and fuel and power engineering systems and further development of creative scientific and technical collaboration with the personnel of enterprises and construction projects according to the experience of the 28 Leningrad organizations which participated in developing the Sayano-Shushenskaya GES; for this the following will be required:

To fulfill the yearly plan on the incorporation of new equipment by all divisions ahead of schedule, by Power Engineering Day;

To draw up before 15 July the working documentation on the volume of construction and installation work on all projects started for 1981; to produce during the year at least 40 percent of the preliminary estimate documentation with an excellent rating;

To achieve economic efficiency from incorporating in the power engineering field scientific research worth at least 3.8 rubles for each ruble of investment on scientific research compared with the 2.5 rubles worth achieved in 1979;

To accomplish a 30 million ruble reduction in the cost of power engineering construction, a savings of 90,000 tons of metal and 100,000 tons of concrete and a 5 million man-day reduction in construction labor costs.

On Aiding Agriculture

Carrying out the resolution of the 25th Party Congress and the July (1978) Plenum of the CPSU Central Committee, the personnel of enterprises and construction projects of the USSR Ministry of Power will give all possible assistance to agricultural workers and will provide for the delivery of machines, equipment, spare parts and materials ahead of schedule.

They will perform work on maintenance and operation of electrical networks and electric power substations worth 400,000 rubles above the plan for kolkhozes and sovkhozes and will provide organizational and technical assistance in performing repair work for electric power installations, grain threshing floors, elevators and other agricultural facilities which take part in crop harvest in 1980 to the amount of 1,950,000 rubles.

They will manufacture and supply to agriculture by internal resources spare parts worth 440,000 rubles.

They will mechanize labor-intensive forms of labor worth 2 million rubles on order of the sovkhozes and kolkhozes.

By Power Engineering Day they will accomplish the ahead-of-schedule activation of a 10-0.4 kilovolt rural electric power transmission line extending 122,000 kilometers including 25 above-plan kilometers in the area of the RSFSR nonchernozem zone.

They will implement at least 95 percent of rural electric power transmission lines on reinforced concrete supports with first-rate and excellent ratings.

They will fulfill ahead of schedule the yearly order of the RSFSR Ministry of Agriculture for the production of 50 portable transformer substations with 250 kilovolt-amperes of power and 10-0.4 kilovolts of voltage and a test group (10 samples) of YaTS-80 cells.

In the Area of Social Development of Personnel

Carrying out the directives of the Party and the Government on raising the living standards of the country, workers of the power engineering sector will direct their efforts toward eliminating a lag tolerated since the start of the five-year plan in the incorporation of living space and projects of social, cultural and general designation, improvement of working and living conditions, educational work with personnel and reinforcement of labor discipline, a reduction in personnel turnover, an expansion of the network of cultural, instructional and sports institutes and the development of a system for economic and mass political work. For these goals they have made the following commitments:

To set up by 1980 courses to increase qualifications in educational combines for at least 121,000 new workers and to increase the qualifications of 420,000 workers and 112,000 engineering and technical workers and 65,000 managers;

To fulfill the 1980 quota of the "Comprehensive Plan for Improving Industrial Hygiene and Sanitation Practices in 1976-1980" by Power Engineering Day;

To incorporate during the year in the cities and villages of power engineers and power builders at least 2,234,000 aquare meters of living space (more than 20,000 square meters ahead of schedule and also 7,000 square meters above the plan), nurseries in 11,850 locations (including 560 locations above the plan), hospitals with 1,450 beds, polyclinics with 4,050 attendance, nonspecialized schools with 12,008 students and trade schools with 5,500 student places.

To reduce personnel turnover by 1.8 percent compared with the 1979 level including 1.2 percent in operation, 3 percent in construction and 1.6 percent in the construction industry;

To incorporate by 1980 in enterprises and construction projects 37 stores 17,758 square meters in area, 66 dining rooms with a seating capacity of 11,383, 15 vegetable and fruit warehouses with a 11,780 ton capacity, 2 dyeing and pickling stations with 1,050 ton capacity, 13 warehouses 19,262 square meters in area and 9 freezers with a 3297 ton capacity.

To fulfill ahead of schedule the overall plan for turnover and supply of products for public nutrition by Glavurs [Main administration of workers' supply]; to sell industrial and food commodities worth 70 million rubles more than were sold in 1979 including 6 million rubles above the plan; to achieve a level of commodity marketing by the self-service method of up to 51 percent;

To obtain at least 1,100 tons of weight gain in swine by using food byproducts of public nutrition enterprises.

In the Area of Environmental Protection

To accomplish building and installation work worth 111 million rubles on the structures of projects for environmental protection.

To repair and rebuild ash traps for 60 hot water heaters of thermal power plants.

To develop:

a). a technical and working plan for an experimental industrial facility for scrubbing sulfur dioxide from flue gases at the Dorogobuzhskaya GRES;

b). measures to protect the basin of the Baltic Sea directed toward preventing contamination by wastes from shale energy conversion at the Estonskaya GRES.

Power engineers and power builders assure the Lenin Central Committee of the Communist Party of the Soviet Union and, personnally, comrade L. I. Brezhnev that they will raise ever higher the banner of socialist competition in order to worthily celebrate the 110th anniversary of V. I. Lenin's birth and to fulfill the 1980 and the 10th Five-Year Plans as a whole ahead of schedule.

The commitments have been considered and adopted in general assemblies of staffs of enterprises and organizations of the USSR Ministry of Power and Electrification and have been approved by the boards of the Ministry and the Presidium of the Central Committee of the trade union of workers of electric power and the electrical engineering industry for an expanded conference on 10 March 1980.

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ELECTRIC POWER

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HYDROELECTRIC POWER PLANTS PROVIDE EFFICIENT FUEL USE

Moscow GIDROTEKHNICHESKOYE STROITEL'STVO in Russian No 5, May 80 pp 20-23

/Article by candidate of technical sciences I. I. Fayn: "On the Economic Estimation of Hydroelectric Power Plant Fuel Efficiency"/

/Text/ The fuel efficiency of a hydroelectric power plant is defined as the difference in fuel consumption at thermal electric power plants of a power system with its development by a designed hydroelectric power plant or by a substituted thermal power plant. Power generation at GES's /hydroelectric power plants/, which amounted to 169.6 billion kilowatt-hours in 1978, is an important factor in providing for savings on fuel and an improvement in the structure of the country's fuel and power production balance. The average relative savings on fuel produced by GES development amounts (in conventional fuel) to 0.4 kilograms of conventional fuel per kilowatt-hour. This has insured a reduction in fuel consumption by thermal power plants resulting from the construction of hydroelectric power plants, considered by us to be the production of power generated by GES's on the average relative fuel savings provided by the construction of hydroelectric power plants. The construction of hydroelectric power plants has made it possible to alleviate the strain on the fuel balance in many regions of the country. This has a special significance in fuel-scarce regions.

Calculations of the average relative magnitude of fuel savings from hydroelectric power plant construction in regions of the USSR at the 1975 level are shown in table 1.

Especially important is the fuel savings which GES's provide in the country's European regions. Without GES's in the European regions it would be necessary to incorporate into a power system an equivalent number of steam turbine and gas turbine power plants based on fuel oil and gaseous petroleum residue which would necessitate a considerable increase in the total consumption of this fuel in USSR electric power plants.

In 1975 nearly 50 billion kilowatt-hours of electric power was generated in the hydroelectric power plants of Siberia with a corresponding savings of nearly 20 million tons of conventional fuel which constituted 35 percent of the volume of Kuznetskiy coal transported from Siberia to the European part of the USSR.

Table 1. Fuel Savings Produced by the Generation of Electric Power by GES's in 1975, according to Region of the USSR

Territory	Electric power generation, billion kwt-hrs.	Fuel savings, million tons of convent. fuel
European territories of the USSR		
Northwest (including the Baltic region and Belorussia)	15.3	6.1
Central region--near the Volga--Urals	26.4	10.6
South	10.0	4.0
Northern Caucasus	3.5	1.4
Transcaucasus	5.3	2.1
Total on European territory and Urals	60.5	24.2
Asiatic territories of the USSR		
Central Asia	7.9	3.2
Kazakhstan	3.9	1.6
Siberia	49.9	19.9
Far East	3.7	1.5
Total on Asiatic territory of the USSR	65.4	26.2
Total for USSR	125.9	50.4

Thus, hydroelectric power plant construction made a significant contribution to the efficiency of the fuel and energy production economy of our country. In the future the contribution of GES's to shaping the fuel and power balance of the country will increase considerably. With a generation of 250 billion kilowatt-hours of power at GES's, the fuel savings will amount to 100 million tons of conventional fuel (including 40 million tons of conventional fuel saved by GES's situated in the European parts of the country).

The fuel savings provided by hydroelectric power plant construction are considerably greater in real terms than the above indicated savings of conventional fuel. The fuel savings provided by GES's are, in monetary terms, the production of a volume of economized fuel and their contingent fuel costs.

Contingent costs for fuel differentiated for various regions of the country represent a system of interconnected relative economic indicators which characterize an economic estimate of costs to the national economy to provide for additional consumption of various forms of fuel and power in areas of the country (1). These relatives indicators are varied in time in accordance with changes in the fuel and power balance and the initial technical and economic indicators.

Due to the objective limitation of the most efficient energy resources, it seems necessary in each given time period to involve more expensive natural sources of energy in the power balance along with the comparatively inexpensive sources. National economic effects of changes in energy resource consumption are also estimated in terms of consumption of the more expensive sources as are the magnitude of their mining or production.

Only those sources available at a given stage may accomplish contingent functions:

The technically feasible scale of mining exceeds the required level of their use in an optimized fuel and energy balance;

The available resources and qualitative characteristics of the fuel make it possible to supply a rather broad group of consumers both in their own region and also outside of it.

Contingent costs for fuel are shaped in a territorial profile for regions directly furnished with fuel from one of the surrounding basins with straightforward addition of the relative costs for its mining and transportation. In the remaining regions some kind of contingent fuel compensates for the variation in fuel consumption only after more or less complicated interregional redistribution of the remaining energy resources. For this reason, the contingent costs for fuel in such regions consist of the variation (increase or decrease) in transportation costs over the entire chain of redistribution of the fuel.

Contingent cost indicators differ not only in territorial profile but also in the types of fuel, thereby making it possible to obtain a monetary estimate of the qualitative heterogeneity of the fuel from the point of view of the consumers. In this case the numerical values of the contingent costs for gas and fuel oil are formed by indicators of the surrounding fuel (coal) with an increase in economy of the costs obtained with the use of high-quality fuel by surrounding consumers.

In the near future Donetskiy fuel coal will be contingent to a large part of the country's European regions. In the more remote future contingent functions will be carried out by atomic power plants. Kansko-Achinskiy brown coal will be contingent in Siberian regions. Because of its inherent physical characteristics it should be used principally in coal-dust furnaces and it also has limited transportability. For this reason the group of consumers of run-of-mine Kansko-Achinskiy coal is relatively narrow and the potential for its refining and use in European regions by means of direct current electric power transmission are limited. As a result of this, coal serves as a contingent fuel in the confines of Siberia and has contingent costs equal to the mining and transportation indicators.

"Guiding Directives" (1),which has been in effect for a number of years, has played a definite positive role in power engineering. However, during recent years the cost indicators for fuel have increased considerably, making it necessary to review the norms set in "Guiding Directives".

Let us consider the norms for contingent costs on Donetskiy coal which have a decisive effect on contingent fuel norms for an entire series of regions in the country's European part.

In "Guiding Directives" (1) the contingent costs for mining Donetskiy fuel coal were estimated at 19-21 rubles per ton of conventional fuel. These costs are based on source information which is already out of date **and** are understated.

According to current data, capital investments for new pit construction for Donetskiy fuel coal are estimated for the future at an average of 70-80 rubles per ton and at 80-90 rubles per ton allowing for the cost of enrichment factories and geological exploration.

The dynamics of change in the domestic net cost of mining Donetskiy fuel coals are presented in table 2.

Table 2. The Dynamics of Variation in the Net Cost of Mining Donetskiy Fuel Coals

Years	Yield	Enrichment	Total
1970	100	100	100
1971	101	96	100
1972	103	93	102
1973	104	92	103
1974	108	92	107
1975	116	102	115

In connection with the indicated existence of a trend toward increasing the wages of workers, the performance of a number of measures associated with improving safety equipment and working conditions, the net cost of mining Donetskiy fuel coal in the future will be, in our opinion, no lower than 10 rubles per ton and, if the net cost of enrichment is added to this, then it will be at least 11 rubles per ton.

The specific nature of the mining industry dictates the presence of so-called mining support costs. These costs are associated with a constant fluctuation in the extent of work areas and also with change in the exploitation process under mountainous conditions. These costs are required even with the unchanged productive capacity of the mining enterprises for maintaining a scale of mining and "support" of its level. When the first prepared longwalls or bore holes are worked out, it is necessary for them to make the next new longwalls or holes with a reduction in the capacity of the layer or its mining to increase the number of effective longwalls or holes and compensate for the lower productivity of each of them.

Capital costs for mine construction before its activation do not provide for obtaining projected products during the planned operating period. As early as a year or two after the start-up of a mine with successive activated and developed longwalls, new longwalls should be prepared and this process is continued until the end of its service period.

Yearly support costs for Donetskiy fuel coal are estimated at 3.0-3.2 rubles per ton.

Relative capital investments for the mining of fuel taking the time factor ($\bar{K}$) into account are defined as

$$\bar{K} = \beta K, \qquad (1)$$

where β is the coefficient of the ratio between the relative capital investments allowing for the time factor and the relative capital investments for mining fuel without taking the time factor into account;

$$\beta = \frac{\Sigma K_t (1 + P_н)^{t_б - t}}{\Sigma \Delta N_t (1 + P_н)^{t_б - t}}; \qquad (2)$$

K is the actual capital investment for mining the fuel; K_t is the capital investment for mining the fuel in terms of a construction year; t is the current construction year; $t_б$ is the base year; P_H is the standard for the time factor; ΔN_t is the increase in the equipment activated for fuel extraction during the year t compared with the year t - 1, in percentages.

The net cost of fuel mining allowing for the time factor $\bar{U}$ is defined by the formula

$$\bar{U} = \Psi U, \qquad (3)$$

where Ψ is the coefficient of the ratio between the net cost of mining taking the time factor into account and the net cost of mining without considering the time factor;

$$\psi = \frac{\Sigma \Delta U_t (1 + P_н)^{t_б - t}}{\Sigma \Delta N_t (1 + P_н)^{t_б - t}}; \qquad (4)$$

U is the cost of fuel without allowing for the time factor; ΔU_t is the increase in the cost of fuel extraction per year compared with the year t - 1, in percentages.

Using the prevailing norms for the duration of construction and the development of activated machinery for mines of the Donetskiy basin (2,3), coefficient $\beta = 1.46$ and coefficient $\Psi = 1.06$.

In the composition of Donetskiy coals scheduled for use in electric power plants, variation in the grade of coals mined in terms of one of the forecasting variations for materials (4) is shown in table 3.

Thus, in the future the share of higher-quality fuel coals A, PA and T will be reduced and there will be increased mining of lower-quality coals of the

G and D types characterized by higher sulfur (3.0-3.3 percent) and ash (25-30 percent) contents.

Table 3. The Grade of Donetskiy Coals Scheduled for Use in Electric Power Plants, in Percentages

Grade	1970	Data for Future
A and PA	69.0	58.4
T	17.2	8.4
D	5.3	7.2
G	4.9	25.2
K, Zh and OS	3.6	0.8
Total	100.0	100.0

In addition to the structural changes, a trend toward lowering the quality of the mined coal has been observed in recent years. In particular, the caloricity of the higher-quality Donetskiy fuel coal of the ASh and T types has been lowered by 7-10 percent over a 15 year period and the ash and moisture contents have increased by 10-15 percent. The progressive increase in ash content of run-of-mine coal will remain at an average 0.3 percent per year in the future (5) since the average capacity of worked out layers will be lowered and the relative weight of complex construction layers will increase with wholesale extraction.

Analysis of the factual data and projected development of the Donbass coal industry indicates that according to the actual combined correlation of coal types and their characteristics, the caloric equivalent of the Donetskiy coal in new mines will be no higher than 0.7-0.71.

The contingent costs for mining Donetskiy fuel coals in new mines in the future, calculated according to the above-presented data on capital investments, net cost, caloric equivalent and duration of construction and development, will amount to 42-45 rubles per ton of conventional fuel.

The future contingent costs for coal in the country's European regions are determined by the costs for mining Donetskiy coal with an increase or decrease in their transportation costs in accordance with the optimum schedule for transportation within the European regions.

We have developed "Tentative Directives for Determination of the Economic Efficiency of Capital Investments in Designing Hydroelectric Power Projects" (6) in which norms for the contingent costs for fuel in 1981-1990 and in 1991-2000 have been presented.

The State Expert Commission of USSR Gosplan, having approved "Tentative Directives" as a whole, considered it advisable to rename it "Methodological Directives for Determining the Economic Efficiency of Capital Investments in the Design of Hydroelectric Power Projects". In addition, in the resolution of the State Expert Commission of USSR Gosplan it was noted that tentatively, until authorization of new directive materials, the contingent costs for fuel in determining the economic efficiency of hydroelectric power projects may be taken to be those in "Tentative Directives", endorsed by the board of the USSR Ministry of Power and Electrification.

In table 4 are cited the contingent costs for fuel coal in the country's European part according to "Guiding Directives" (1) and according to the norms recommended by us in "Tentative Directives" (6). The contingent costs for 1981-1990 have been adopted in (6) in agreement with the supplement to the above-mentioned "Guiding Directives" prepared by the scientific council of the USSR Academy of Sciences on the comprehensive problems of power engineering presented to USSR Gosplan.

Table 4. Contingent Costs for Fuel Coal in the European Part of the Country, Rubles per Ton of Conventional Fuel

Region	Guiding Directives	Tentative Directives	
		1981-1990	1991-2000
Northwest	19-22	35-58	46-49
Central region	18-21	34-36	45-48
Northern Caucasus	20-22	32-34	43-46
Near the Volga	17-20	30-34	43-46
Urals	13-16	25-28	39-42
Eastern Ukraine, Rostovskaya oblast	19-21	31-33	42-45
Western Ukraine, Moldavia	20-23	33-35	44-47
Georgia	20-23	33-35	44-47
Armenia, Azerbaijan	21-24	35-37	45-48

Table 5. Contingent Costs for Natural Gas in Central Asia, Rubles per Ton of Conventional Fuel

Region	Guiding Directives	Tentative Directives	
		1981-1990	1991-2000
Turkmenia	14-17	28-30	39-42
Uzbekistan	15-18	29-32	40-43
Tadzhikistan	15-18	31-33	40-43
Kirgizia	16-18	30-32	41-44

Table 6. Prices on the World Energy Market in the Middle of April, 1977 (in dollars per ton of product)

Oil product	Italian ports*	Rotterdam**
Premium gasoline	142-146	144-154
Regular gasoline	127-129.5	132-138
Kerosene fuel for jet engines	122-124	127.5-129.5
Diesel fuel	116.5-118.5	117.5-119.25
Heavy-duty fuel oil with sulfur content of:		
1%	80-82	83-85
3%	71-73.5	71.5-73.5

* Delivered by tanker
**Delivered by barges

Contingent costs for natural gas in Central Asia according to "Guiding Directives" (1) and according to "Tentative Directives" (6) are shown in table 5.

Now let us consider the norms for contingent costs for Kansko-Achinskiy brown coal. In "Guiding Directives" (1) the contingent costs for mining Kansko-Achinskiy coal are estimated at 2.5-3.5 rubles per ton of conventional fuel. These costs are also based on already outdated information.

According to current data, the capital investments for mining Kansko-Achinskiy brown coal come to 13.0 rubles per ton (including 9.65 rubles per ton in industrial construction; 3.35 rubles per ton are the capital investments for regional construction and the production base). In addition, centralized capital investments on geological exploration work amounting to 0.7 rubles per ton must be accounted for. Thus, capital investments for mining Kansko-Achinskiy brown coal (allowing for geological exploration) amount to 13.7 rubles per ton.

The net cost of mining Kansko-Achinskiy coal is expected to be two rubles per ton in the future; support costs in the amount of 0.44 rubles per ton yearly and a 0.5 caloric equivalent are expected.

Relative capital investments and net costs for mining Kansko-Achinskiy brown coal taking the time factor into account are determined using formulas (1) to (4). The quantitative value of coefficient β for Kansko-Achinskiy coal has been defined as 1.32 while the quantitative value of coefficient Ψ is 1.11.

In "Tentative Directives" the contingent cost norms for Kansko-Achinskiy coal are recommended as: 6-8 rubles per ton of conventional fuel in 1981-1990 and 6-10 rubles per ton of conventional fuel in 1991-2000.

Peak-load hydroelectric power plants and pumped-storage electric power plants in the European part of the USSR often are comparable to gas turbine power plants operating on diesel fuel oil or on gas.

With a certain amount of oil extraction and production of oil products and complete satisfaction of the needs of industry for industrial stocks, the oil products saved in power engineering may be exported.

The export value of oil and oil products is determined to a considerable degree by prices in the world energy market. The energy crisis which is shocking the capitalist world has found its main expression, as is known, in a sharp jump in prices for the majority of basic forms of energy resources. Thus, during 1971-1973 oil prices rose 6.5-fold and remain now at a high level on the order of 90-100 dollars per ton depending on the quality of the oil. The price for oil products on the world market according to scientific research data of the Business Conditions Institute (7) is shown in table 6.

In the opinion of Soviet economists, the general trend in oil prices on the world energy market has become irreversible (8). If any change occurs in the prices of oil and oil products, then it will be an increase.*

The contingent cost norms for diesel oil products are estimated to be 80 rubles per ton of conventional fuel for 1991-200 and 63-65 rubles per ton of conventional fuel in the near future (1981-1990). These norms and the data in table 4 have been adopted in (6).

Using the recommended contingent cost norms for fuel significantly increases the economic impact of the projected hydroelectric power plant construction and increases the economic potential of hydroelectric power resources.

Conclusions

Hydroelectric power plants provide a considerable savings in fuel. The new contingent fuel cost norms developed and approved by the USSR Ministry of Power and Electrification and issued for use by USSR Gosplan are based on current estimates of costs for its mining and on the fluctuating fuel and energy situation. The economic efficiency rating of planned hydroelectric power projects is considerably increased with the calculation of the recommended norms.

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* At present, prices on the world energy market have increased still more.

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CSO: 1822

ELECTRIC POWER

GENERATING CAPACITY OF POWER PLANTS IS UPGRADED

Moscow GIDROTEKHNICHESKOYE STROITEL'STVO in Russian No 5, May 80 p 46

/"Article: "Chronicle of Construction and Operation"/

/"Text/ On 2 March power builders of advanced mechanized tower No 33 of the Zapadkarakumgidrostroy trust poured the final cubic meters of concrete in the dam separating the Caspian Sea from the bay of Kara-Bogaz-Gol. The dam is 55 meters long and 6.5 meters high with a gentle incline. It was erected using local building materials. The first-ever hydroelectric power plant structures span the strait on unstable quicksand with a rather strong current.

The dam, in conjunction with a reliable throughput structure, makes it possible not only to be aided by the Caspian Sea but also to regulate the output of water entering from the strait in judicious limits, maintaining in it the required concentration of brine.

A hydraulic turbogenerator for the Yuzhkozerskaya hydroelectric power plant on the Kem' River in Karel'skaya ASSR was put into operation in March this year.

By January 1980 the Nurek hydroelectric powerplant had generated 25 billion kilowatt-hours of electric power since the day its first units were started up and completely justified its construction costs.

Construction has begun on a unique complex of structures which will protect the city of Leningrad from flooding. The engineering project is being carried out by the Leningrad division of the Gidroproyekt Institute imeni S. Ya. Zhuk with the participation of more than 50 scientific and planning organizations. A network of rock and earth levees will traverse the Finnish strait. Their overall length will be 25 kilometers. Between the levees will be constructed two openings for the passage of ships and six water-passage structures. On the north bank of the Finnish strait in the area of Lisiynos Cape machine operators of Lengidroenergospetsstroy have begun work on the construction of structures to protect Leningrad from flooding.

The biggest mud and rock slides do not scare the industrial enterprises, transport supply lines and living groups of the western part of the capitol of Kazakhstan. They are reliably protected from the menacing element originating high in the mountains by a heavy-duty dam bridging the valley of the Bol'skaya Almaatinka River. In March the final cubic meters of concrete were poured in its body. The high efficiency of similar structures in the struggle against mud flows has been proved in practice. A stone rubble dam near the world-famous high-mountain skating rink Medeo not so long ago stood up to the pressure of an enormous mud slide. Both dams are included in a system to protect the city of Alma-Ata from the mountainous elements.

The highest dam in the world (335 meters) will be erected as part of the hydroelectric power system of the Rogunskaya hydroelectric power plant on the Vakhsh River in Tadzhikistan in a zone of 9-intensity seismic activity. The Institute for Earthquake-proof Construction and Seismology of the Tadzhik SSR Academy of Sciences experimented on a 1:300 scale model to establish the load on a dam with various sizes and types of earthquakes, to determine its resilience and, in accordance with the obtained results, to make recommendations on designing and constructing the dam.

At the beginning of March this year, filling of the Kopetdagskiy reservoir was completed. First, 220 million cubic meters of water were accumulated in it. Other Turkmenskiy reservoirs were also filled to the control mark. In them have been accumulated 1.6 billion cubic meters of water. This will provide for irrigation of young crops of cotton and other agricultural crops.

Construction has been started on the fourth phase of the Stavropol'skiy Canal. The new structure of the largest reclamation system of the Northern Caucasus extends 97 kilometers into the arid regions, which will provide the opportunity to intensify agricultural production. With this phase under construction, the length of the Bol'shoy Stavropol'skiy Canal will reach 359 kilometers. It will extend from the foothills of the Northern Caucasus almost to the Kalmytskiy Steppes where the lands of Stavropol' come together in the north. Putting into operation the fourth phase of the canal will make it possible to irrigate an additional almost 80,000 hectares of arid land.

In the Armenian SSR high in the mountains, developers of the republic are completing construction of the Dzhogazskiy reservoir. This is one of the largest in Armenia. Spread over a 214 hectare area, it holds more than 45 million cubic meters of water. The dam of this reservoir is 60 meters high. The reservoir will provide the potential for irrigating more than 5,000 hectares of arid land and to comsiderably improve water provision for existing vineyards and fruit orchards.

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ELECTRIC POWER

GAS-TURBINE, STEAM-GAS UNITS CHARACTERISTICS DESCRIBED

Moscow PROMYSHLENNOYE TEPLOVYYE ELEKTROSTANTSII in Russian signed to press 1979 pp 120-140

[Chapter 7 from "Promyshlennoye teplovyye elektrostantsii" (Industrial Thermal Electric Power Stations), Izdatel'stvo "Energiya", 1979, pp 120-140]

[Text]

7-1. Characteristics of Heat Release from GTU's (Gas-Turbine Units)

Gas-turbine units may be used with great efficiency for the combined production of heat and electric power. The conditions of heat release from GTU's have the following characteristics, which are determined by the conditions and field of their efficient utilization:

1. The GTU cycle is characterized by high temperatures of the heat feed-in and outlet; hence the temperature of the gases fully developed in the power cycle amounts to 300--500°C and is sufficient for heating up the external heat carriers to the temperatures necessary for the consumers.

2. Heat and hot water are released from GTU's by utilizing the heat of the exhaust gases and the water which cools the compressors (Fig. 7-1), i.e., heat which is fully developed in the given power cycle. Hence:

a) the temperature level of the heat being released has hardly any influence on savings of $B_{эк}$ based on the combined production of heat and electric power.[1] As is known, in the case of steam-turbine units the temperature level of the released heat exerts a great influence on their economizing features.

b) in a GTU the capacity of the engine, expenditure of fuel, expenditure of the operating medium (gas), the temperature and pressure of the operating gas at individual points during any possible heat release remain just the same as during operation on a purely power schedule.

Thus, fuel expenditure in a GTU is determined solely by its electrical capacity and does not depend upon the amount of heat being released. In a PTU (steam-gas unit) a heat release $Q_{з.п}$ at a constant capacity brings about an increase in the heat expenditure of fuel as follows:

$$\Delta Q_{\text{топ}} = Q_{\text{в.п}}\xi/\eta_{\text{пг}},$$

where ξ is the coefficient of heat value from a given bleeding of the turbine.

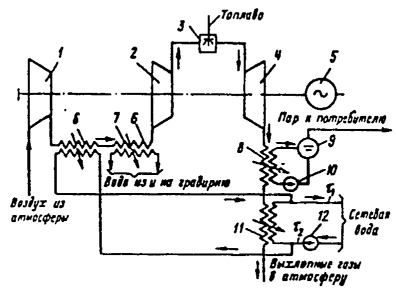

Figure 7-1. Schematic of heating GTU (simplified)

Key:

1. Low-pressure compressor
2. High-pressure compressor
3. Combustion chamber
4. Gas turbine
5. Electric generator
6. High-temperature section of air-cooler
7. Low-temperature section of air-cooler
8. Heating surface of steam generator on exhaust gases
9. Drum separator of steam generator
10. Circulating pump of steam generator
11. Heating surface of network-water preheater
12. Network pump

3. A high initial gas temperature before the turbine (cycle) may also be utilized in a GTU with a modest standard capacity, while maintaining high internal efficiencies of the turbines and compressors; hence the energy indicators of a heating GTU depend relatively little on its uniform capacity, whereas in steam turbines high initial steam parameters of 13.0--24.0 MPa (megapascals) are utilized only with a standardized turbine capacity of 50--200 MWt (megawatts). In connection with this, heating GTU's may provide fuel savings in comparison with separate heat and electric power supply (KES [condensation electric power stations] plus boilers) also at modest-level heat loads in which steam-turbine TETs's (heat and power stations) are not economically justified. This is especially important for medium and small industrial enterprises, cities, etc.

4. The complete cost of an installed kilowatt of a heating GTU amounts to no more than 100--120 rubles. The proportionate cost of large-scale KES's is equal to 120--140 rubles per kilowatt. The staff coefficient at a gas-turbine TETs (GTETs) is approximately the same as at a rayon-level KES.

Therefore, with equal closing outlays for fuel for a GTETs and a KES, the GTETs is economical in all cases, when it provides a fuel economy, whereas the economically optimum coefficient of heating a GTETs $\alpha^{\Gamma}_{Т\ni Ц}$ is usually more than the optimum $\alpha^{\Gamma}_{Т\ni Ц}$ with regard to electric-power indicators.

5. At the present-day level of energy systems' development steam-turbine TETs's are economically justified at a rated heat load of no less than 400--450 MW (350--430 Gcal. per hour) in the European part of the USSR and 500--600 MW in regions with cheaper fuel. Gas-turbine TETs's, thanks to the characteristics enumerated above, are economically justified at loads of 100--400 MW and even lower. This circumstance broadens very greatly the field of the economic use of introducing district heating systems, since consumers with loads of 100--500 MW expend about 25 percent of all the heat consumed in the USSR. Broadening the field of introducing district heating systems while building gas-turbine TETs's may yield great savings in fuel and monetary funds.

6. Inasmuch as the temperature of the hot water released from a GTETs has practically no influence on fuel savings, the economically optimum water temperature in the supply line of network τ_1 from a GTETs is considerably higher than from a PTETs, and it amounts to 200--230° C with an independent system of connecting customers.

It is becoming more profitable to have quantitative regulation (with τ_1 as a constant), within which the expenditure of network water determining the diameter of the heat pipelines is considerably less than the expenditure of water corresponding to the maximum winter load. Due to the two factors noted above, pipeline diameters are obtained which are significantly less than when $\tau_1 = 150°$ C, as well as due to a qualitative regulation, which substantially reduces the cost of heat networks and their metal consumption and increases the economic radius of the centralized heat supply.

At a high water temperature in the network's supply line it is possible to obtain low-pressure steam in places in the water-steam vaporizers. This may provide great savings in the heating systems of rayons in which, together with hot water, certain consumers require low-pressure steam for production.

The exhaust gases of a GTU may be used economically to heat up high-temperature heat carriers (VOT) to 300--400° C; such heat carriers have a number of production uses.

7. GTETs steam generators are heated up by exhaust gases with temperatures no higher than 400--500° C. The steam pressure in them is low, ranging from 1.2 to 1.8 MPa. Therefore, as the experience of industrially utilized steam generators has shown, GTETs steam generators can operate completely on cationized water. This circumstance is of great importance for enterprises with large condensate losses. At such enterprises with high-pressure TETs steam turbines we need to build much more expensive and complex desalinizing or steam-converting units.

8. In order to cover the peak loads of both steam as well as heating steam generators, network preheaters operating on GTU exhaust gases may also be boosted by sub-heating, in which by means of igniting fuel the temperature of the gases is raised to the required level. Inasmuch as in the sub-heating the fuel is burned by means of the oxygen contained in the exhaust gases, the sub-heating does not, for all practical purposes, increase the quantity of the unit's escaping gases, their temperature increases only comparitively insignificantly. This is explained by the sharp increase of the temperature pressure in the heat exchangers. Thus, without increasing the area of the heating surface, the heat capacity of the steam generator and the network preheaters can be sharply stepped up. Inasmuch as sub-heating practically does not increase the total outflow of escaping gases, the heat of the fuel additional burned in sub-heating is utilized with an efficiency of about 0.9 and higher, depending upon the degree of boosting.

In connection with what has been indicated, we cannot install special peak boilers at a gas-turbine TETs's along with steam generators and reduce corresponding expenditures. In cases where a GTU is not operating it is possible to burn fuel for sub-heating in the open atmosphere. This guarantees nominal heat conductivity of the heat generators and network pre-heaters, but at a lowering of efficiency.

The characteristics enumerated above indicate that GTU's are heating aggregates with extremely good future prospects and a good supplement for steam-turbine TETs's; in particular, they allow for considerable expansion in the field of economically utilizing the introduction of district heating systems. However, the impossibility of operating disconnected GTU systems on solid fuels limits the sphere of their utilization.

7.2 Determining the Fuel Economy of a Heating GTU, Selecting a Schematic and Equipment for the Units

For any unit--steam-turbine, gas-turbine, or steam-gas--the fuel economy, to be obtained on the basis of the combined $B_{эк}$ production, in comparison with an individual power supply (KES plus boiler-type), is determined by the formula (2-1).

Inasmuch as GTU's for the release of heat to outside consumers from turbines $Q_{в.п}^{тур}$ utilize the heat of gases which have been produced entirely within the power cycle, the fuel expenditure for a GTU is determined solely by its electrical capacity and remains practically the same during both the maximum possible release of heat of various parameters as well as when operating on a purely power schedule. Accordingly, in the case of any heat releases which are possible for a given GTU:

$$Q_{ГТУ}^{топ} = q_{ГТУ}^{э} N_{ГТУ}^{э}, \qquad (7\text{-}1)$$

where $Q_{ГТУ}^{топ}$ is the expenditure of the fuel heat of a heating GTU, $N_{ГТУ}^{э}$ is the GTU's electrical capacity, $q_{ГТУ}^{э}$ is the proportional expenditure of fuel heat per kW-hr.

If the efficiencies of the GTU's and the KES's were equal, then the expenditure of fuel to produce electric power in the case of a GTETs and a separate electric power supply would be the same $(B_{КЭС} = B_{ГТЭЦ})$, while the savings in conventional fuel would amount to $B_{эк} = B_{кот}$ or $B_{эк} = Q^{тур}_{в.п}/\eta^{н}_{кот}$, where $Q^{тур}_{в.п}$ is the heat released to outside consumers by virtue of the heat produced by GTU's, while $\eta^{н}_{кот}$ represents the efficiency of the boiler-types being replaced (net).

Usually, however, $\eta_{ГТУ} < \eta_{КЭС}$ or $q^{э}_{ГТУ} > q_{КЭС}$. Taking this factor into consideration,

$$Q_{эк} = Q^{тур}_{в.п}/\eta^{н}_{кот} - Э_{ГТУ}(q^{э}_{ГТУ} - q_{КЭС}), \tag{7-2}$$

where $Э_{ГТУ}$ is the release of electric power from a GTU.

The proportional savings in fuel heat per released unit of heat $q_{эк}$ amounts to the following:

$$q_{эк} = Q_{эк}/Q^{тур}_{в.п} = 1/\eta^{н}_{кот} - Э_{ГТУ}/[Q_{в.п}(q^{э}_{ГТУ} - q_{КЭС})]. \tag{7-3}$$

Inasmuch as with the GTU's the release of heat does not affect the power cycle, the amount of heat $Q^{тур}_{в.п}$ being released from the turbine to the outside consumer may be determined from the GTU's heat balance:

$$Q^{ГТУ}_{топ} = q^{э}_{ГТУ}N^{э}_{ГТУ} = \frac{N^{э}_{ГТУ}}{\eta_{эм}} + Q^{тур}_{в.п} + Q_{у.г} + Q_{у.в} + Q_{о.с}, \tag{7-4}$$

where $\eta_{эм}$ is the electromechanical efficiency of an aggregate, $Q_{у.г}$ is the heat carried off by the escaping gases after they are used by the heat exchangers (See Figure 7-1), $Q_{у.в}$ is the heat carried off by the water from the intermediate air coolers of the compressors, $Q_{о.с}$ represents the heat losses into the environment via the exterior surface. These losses usually constitute no more than 1 percent $Q^{топ}_{ГТУ}$ and they are not considered;

$$Q_{у.г} = c_p G_т (t_{у.г} - t_{н.в}) = N^{э}_{ГТУ} g c_p (t_{у.г} - t_{н.в}), \tag{7-5}$$

$g = G_т/N^{э}_{ГТУ}$ is the proportional expenditure of the working medium (gas) of a GTU, c_p is the gas's proportional heat consumption, $t_{у.г}$ is the temperature of the escaping gases after being utilized by the heat exchangers, $t_{н.в}$ is the temperature of the outside air (the heat balance is compiled from $t_{н.в}$).

The heat given off by the air in the intermediate coolers of the compressors may be fully or partially utilized. Thus, in the case of an immediately available water reservoir, when the addition of chemically purified water to the heat network at a TETs is great, the air in the PO's (intermediate coolers) may be completely cooled by additional water coming in from the chemical purification system with a sufficiently low temperature. Since the air coolers are always made of non-ferrous metal, the make-up water is supplied to them prior to the de-aerator.

When the air in the PO's may be cooled only by feedback network water having a temperature of 45--70° C, then the air in the corresponding section of the PO (See Figure 7-1, No. 6) may be cooled by this water only to 55--80° C. Further cooling of the air to the required temperature (usually 35° C) must be carried out in another section of the PO (No. 7), by cooled water from the cooling tower, river, and the like. The heat which is carried off by water from this section, $Q_{у.в}$ is dissipated into the surrounding environment as follows:

$$Q_{у.в} = c_p G_к \Delta t^{ух}_{воз} = c_p g N_в \Delta t^{ух}_{воз}, \quad (7\text{-}6)$$

where $\Delta t^{ух}_{воз}$ is the difference in the temperatures of the air between its entry and exit from the PO section, to be cooled down by water from the cooling tower. In the model values of temperatures of the cooling water cited above

$$\Delta t^{ух}_{воз} = (55—80) - 35 = 20 \div 55° \text{C}.$$

Let us introduce the following concepts:

a) heat capacity of a GTU $Q_{т.м}$, equal to the maximum quantity of heat which may be released to consumers in a unit of time from a given GTU at its full electrical capacity;

b) coefficient of utilization of a GTU's heat capacity during the period under examination $Z = Q^{тур}_{в.п}/Q_{т.м}$.

The escaping gases and the air being cooled in PO's have low and closely interrelated temperatures. The composition of the escaping gases with the coefficient of excess air $\alpha = 4 \div 7$ is little different than air. Therefore, the values c_p in the formulas (7-5) and (7-6) may be considered with sufficient precision to be equal. One may also regard as equal the mass expenditures of gas through the turbine and the compressor.

Taking into comparative account the stated equation (7-4) and (7-6) and carrying out a regrouping of the terms, we find:

$$\begin{aligned} Q^{тур}_{в.п} &= N^{э}_{ГТУ} q^{э}_{ГТУ} - \\ &- [N^{э}_{ГТУ}/\eta_{эм} + N^{э}_{ГТУ} g c_p \times \\ &\times (t_{у.г} - t_{н.в} + \Delta t^{ух}_{воз})]. \quad (7\text{-}7) \end{aligned}$$

From the equation (7-7)

$$\frac{Q^{\text{тур}}_{\text{в.п}}}{N_{\text{эг}}} = q^{\text{э}}_{\text{ГТУ}} - 1/\eta_{\text{эм}} - c_p g \times$$
$$\times \left(t_{\text{у.г}} - t_{\text{н.в}} + \Delta t^{\text{ух}}_{\text{воз}}\right). \qquad (7\text{-}8)$$

By substituting the found values $Q^{\text{тур}}_{\text{в.п}}/N^{\text{э}}_{\text{ГТУ}}$ or, what is the same thing, $Q^{\text{тур}}_{\text{в.п}}/Э^{\text{э}}_{\text{ГТУ}}$ in the expression (7-3) and utilizing the function $Q^{\text{тур}}_{\text{в.п}} = Q_{\text{т.м}} Z$, we find the proportional fuel heat savings per unit of heat released to outside consumers (in a dimensionless form) as follows:

$$q_{\text{эк}} = 1/\eta^{\text{н}}_{\text{кот}} -$$
$$- \frac{q^{\text{э}}_{\text{ГТУ}} - q_{\text{КЭС}}}{q^{\text{э}}_{\text{ГТУ}} - 1/\eta_{\text{эм}} - g c_p \left(t_{\text{у.г}} - t_{\text{н.в}} + \Delta t^{\text{ух}}_{\text{воз}}\right)} \frac{1}{Z}. \qquad (7\text{-}9)$$

From the formula (7-7) it follows that with Z = 1

$$Q_{\text{т.м}} = N^{\text{э}}_{\text{ГТУ}} \left[q^{\text{э}}_{\text{ГТУ}} - 1/\eta_{\text{эм}} - g c_p \times\right.$$
$$\left.\times \left(t_{\text{у.г}} - t_{\text{н.в}} + \Delta t^{\text{ух}}_{\text{воз}}\right)\right]. \qquad (7\text{-}10)$$

In order to determine $Q_{\text{т.м}}$ in accordance with formula (7-10), the values $t_{\text{у.г}}$ and $\Delta t^{\text{ух}}_{\text{воз}}$ are taken as minimal with regard to technical and economic considerations. In the formula (7-7) the values of these magnitudes are determined by the degree of utilization of a GTU's heat capacity in the case under consideration (i. e., by magnitude Z) and may reach their maximum values for a given GTU.

In using calculations within the SI (International System of Units) system of units in the formulas (7-9) and (7-10) the proportional expenditure of operating gas g is expressed in kg (kilograms)/kJ (kilojoules) /if c_p is expressed in kJ/(kg $\cdot$ °C)/. The manufacturing plants usually cite g in kg/(kW $\cdot$ hrs.). The proportional expenditure of the operating element, expressed in kg/kJ, is 3600 times less than that expressed in kg/(kW $\cdot$ hrs.).

In using calculations within the MKGSS /not further identified/ system of units in these formulas the multiplier $1/\eta_{\text{эм}}$ is replaced by the multiplier $860/\eta_{\text{эм}}$.

The expression $Q_{\text{т.м}}/N^{\text{э}}_{\text{ГТУ}} = q_{\text{тм}}$ represents a GTU's proportional heat capacity, i. e., the amount of heat which may be released per unit of a GTU's electrical capacity.

The reciprocal $N^{\text{э}}_{\text{ГТУ}}/Q_{\text{т.м}}$ represents the proportional production of electric power per unit of released heat.

Of the GTU's characteristics only the following two magnitudes are included in the formula (7-9): $q^{э}_{ГТУ}$ (or the GTU's efficiency) and g, which are known in accordance with the data of the manufacturing plants.

The value $t_{у.г}$ is determined by economic considerations and depends primarily upon the temperature of the heat carrier being heated. In the case of a directly available water reservoir the magnitude $\Delta t^{ух}_{воз}$ is equal to zero, while in other cases it is determined from the expression $\Delta t^{ух}_{воз} = t_{о.в} + \Delta t^{х}_{п.о}$, where $t_{о.в}$ is the temperature of the cooling water at the entrance to the high-temperature section of the PO (for example, the temperature of the feedback network water). The temperature pressure at the cold end of the PO is usually equal to $\Delta t^{эс}_{п.о} = 10 \div 15° C$.

Let $\eta^{э}_{ГТУ} = 0.29$; $g = 16$ kg/(kW-hr)[3]; $b_{КЭС} = 340$ g/(kW . hrs); $\eta^{н}_{кот} = 0.88$; $t_{у.г} = 110° C$; $t_{н.в} = -5° C$; directly available water reservoir; $\Delta t^{ух}_{воз} = 0$; $\eta_{эм} = 0.98$. The GTU's heat capacity is utilized fully, $Z = 1$ (winter). Substituting these values in the formula (7-9), we find $q_{эк} = 0.78$.

If during the period under consideration, for example, one hour, a GTU releases to consumers $Q^{тур}_{в.п} = 665$ GJ/hr., then the hourly fuel savings will amount to $B_{эк} = q_{эк}Q^{тур}_{в.п} = 0.78 \cdot 665 = 516$ GJ/hr., or 16.7 tons per hr. of conventional fuel. In the case of the T-100-130/565 steam turbine, when operating with a full heat load $q_{эк} = 0.80 \div 0.83$[4]. Thus, with respect to the electric-power indicators during full heat load the units under consideration differ little from each other.

In order to determine the annual fuel savings provided by the TGTU's, it is necessary that the annual heat-load schedule (a summation of steam and hot water) be divided into several parts, within which the averaged-out values of Z, may be considered equal, dependent on the heat-load schedule (See Figure 7-3), as well as the values $q^{э}_{ГТУ}$, and g, dependent on the temperature of the outside air. The planned values $q^{э}_{ГТУ}$ and g, dependent on $t_{н.в}$ for GTU's of the GT-100-750-2 are shown in Figure 7-2.

The average annual values $q_{эк}$ may be distinguished from the values corresponding to complete heating charging for GTU's and PTU's, depending on the performances of the aggregates on the power schedule, climatic conditions, the proportion of hot water supply, the summer expenditure of heat for air conditioning, etc. Hence, comparisons between the different types of GTU's and PTU's must be made on the basis of average annual values of $q_{эк}$.

The proportional production of electric power at a heating consumption of $g^{т}_{ТЭЦ}$ at steam-turbine TETs's with a release of production steam is approximately half that under the a heating load and, consequently, the fuel savings are also less per unit of released heat. In the case of gas-turbine TETs's fuel savings practically do not depend upon the temperature level of released heat. Consequently, if under a heating load a a GT-100-750-2-type GTU yields a fuel savings only slightly less than a T-100-130/565-type PTU, then it ought to be notably more economical than a PTU of the same parameters with industrial bleedings.

Of great importance for gas-turbine as well as steam-turbine TETs's is the correct choice of a heating coefficient $\alpha_{ТЭЦ}$. As the total heat capacity of a GTU being installed increases $\Sigma Q_{т.м}$, there is a decrease in the degree of its utilization Z, and, consequently, in its average annual value $q_{эк}$ in accordance with the formula (7-9). Evidently there is a certain crucial (critical) value $Z_{кр}$, under which $q_{эк}$ is reduced to zero. The value $Z_{кр}$ is determined in accordance with the formula (7-9) when $q_{эк} = 0$:

$$Z_{кр} = \frac{\left(q^{э}_{ГТУ} - q_{КЭС}\right)\eta^{н}_{к\,от}}{q^{э}_{ГТУ} - 1/\eta_{эм} - gc_p\left(t_{у.г} - t_{н.в} + \Delta t^{ух}_{воз}\right)}. \qquad (7\text{-}11)$$

Under the conditions of the numerical example considered above $Z_{кр}$ = 0.33 (Line I-I in Figure 7-3), Let us examine the methods for determining the optimum value for the heating coefficient $\alpha_{ТЭЦ}$ with the aid of the annual schedule for steam and heating loads, as shown in Figure 7-3. The heat capacity of the TGTU's being installed, as determined by the formula (7-10), is shown in Figure 7-3 by the lines $Q_{т.м}$, $2Q_{т.м}$, $3Q_{т.м}$, $4Q_{т.м}$ depending on the number of TGTU's. The nature of the lines $Q_{т.м} = f(t_{н.в})$ in Figure 7-3 corresponds to a regeneratorless GTU with one PO and one PP. Among the regenerator-type GTU's in accordance with the simple schematic the value $Q_{т.м}$ with a reduction of $t_{н.в}$ decreases considerably more intensively.

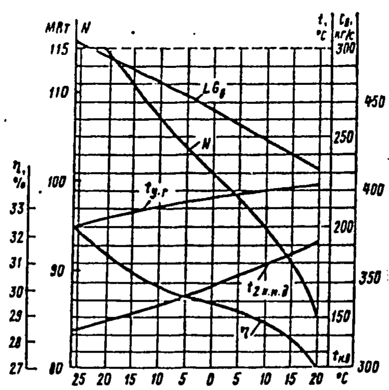

Figure 7-2. Indicators of the GT-100-750-2 GTU, Dependent on the temperature of the Outside Air

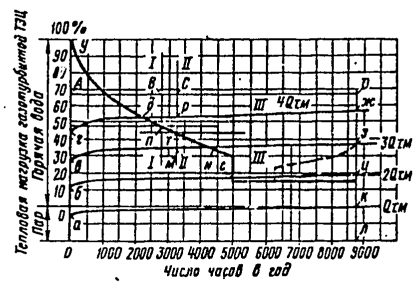

Figure 7-3. Annual Heat-Load Schedule of a Gas-Turbine TETs

In Figure 3 it may be seen that when two GTU's are installed at a given GTETs $Z^{год} \approx 1$. The utilization coefficient of the third GTU's heat capacity is

$$Z_3 = \frac{\text{пл. } б\text{-}в\text{-}н\text{-}с\text{-}б}{\text{пл. } б\text{-}в\text{-}з\text{-}и\text{-}б},$$

i. e., considerably more than $Z_{кр} \rightarrow = 0.33$, particularly under the summer load for air conditioning (shown by a dotted line in Figure 7-3). Consequently, it remains to be established whether or not the installation of a fourth TGTU $(4Q_{т.м})$ will provide additional fuel savings.

For the fourth TGTU

$$Z_4 = \frac{\text{пл. } в\text{-}г\text{-}р\text{-}м\text{-}в}{\text{пл. } в\text{-}г\text{-}ж\text{-}з\text{-}в}.$$

It may be considered with sufficient precision that for the fourth TGTU

$$Z_4 = \frac{\text{отрезок } AC}{\text{отрезок } AD},$$

$$Z_{кр} = \frac{\text{отрезок } AB}{\text{отрезок } AD} = 0{,}33,$$

where AB, AC, and AD are segments on the load schedule. Inasmuch as AC > AB, the fourth TGTU will provide additional fuel savings, albeit much less than the third TGTU.

Previously the value Z_4 for the fourth TGTU was determined by derivation from its operation at full capacity during the course of an entire year.

Taking planned summer repairs into consideration, the total downtime of the four GTU's amounts to 2500--3000 hours per year. Accordingly, the following is provisionally true:

$$Z'_4 = \frac{\text{пл. } в\text{-}г\text{-}р\text{-}м\text{-}в}{\text{пл. } в\text{-}в\text{-}III\text{-}III\text{-}в},$$

i. e., much more than critical.

As already noted, the GTETs's have an economically optimum coefficient of $\alpha_{\text{тэц}}$, as a rule, more optimum with regard to electric-power engineering, in which the maximum fuel savings are achieved. Therefore, the question of the feasibility of installing a fourth TGTU should be resolved with consideration being given to the specific conditions of the given TETs, the utilization of the GTU for covering peak electric-power loads, etc. When there is a greater proportion of steam loads, the number of turbines must be chosen with consideration being given to the potential steam productivity of the steam generators [52]. The physical sense of $Z_{\text{кр}}$ in accordance with the formula (7-11) and that of $\lambda_{\text{экс}}$ in accordance with the formula (2-32) are the same. Their numerical values determine the value $\alpha_{\text{тэц}}$, when the latter is exceeded, an additionally installed capacity unit of the heating aggregate provides not a saving but an overexpenditure of fuel in comparison with the individual variant ($\Delta B_{\text{эк}}$ becomes negative).

In regenerator-type heating GTU's switching off the regenerator increases heat release to the consumers by $\Delta Q^{\text{тур}}_{\text{в. п}}$ (See § 6-2) but increases by an equal amount the expenditure of fuel heat in the combustion chamber $\Delta Q^{\text{тур}}_{\text{в. п}} \approx \Delta Q_{\text{к. с}}\eta_{\text{к. с}}$. As a result, an additional heat release to the consumers $\Delta Q^{\text{тур}}_{\text{в. п}}$ occurs at the expense of heat from additionally burned fuel. Hence in the case where regenerator-type GTU's are installed, the values $Q_{\text{т. м}}$, which have been inserted in the schedule of Figure 7-3, are more convenient to calculate when the regenerator is switched in. In this case the heat being measured out by the area $г\text{-}у\text{-}д\text{-}г$, will be released by means of lowering the degree of regeneration or sub-heating of the heat-using units (or a unit of the special peak boilers). In the case of non-regenerator-type GTU's the heat being measured out by the area $г\text{-}у\text{-}д\text{-}г$, is released by means of sub-heating.

In both instances the annual expenditure of fuel heat at GTETs's depends solely on their electrical capacity $Q^{\text{год}}_{\text{топ}} = \Sigma\,(Э^{э}_{\text{ГТУ}} q^{э}_{\text{ГТУ}})$ plus the expenditure for heat being released at the expense of heat from additionally burned fuel (area $г\text{-}у\text{-}д\text{-}г$) taking into consideration the efficiency of sub-heating, the efficiency of the combustion chamber (at regenerator-type GTU's), or the efficiency of a peak boiler.

If the variant is considered with a GTU unit which was designed as a regenerator-type but without regenerators, then in order to determine $\bar{q}_{\text{эк}}$ in accordance with the formula (7-9), we need to insert into it the value

$q'_{\text{ГТУ}}$, corresponding to operation without a regenerator.

At GTETs's utilization heat-exchangers (UT's) are being heated by gases with a temperature no higher than 400--500° C (See Figure 7-1). At such a temperature, for all practical purposes, only a convective heat exchange takes place, and the coefficient of heat yield from the gas to the pipes is inversely proportional to their diameter; therefore, UT pipes usually have a diameter of 22--38 mm.

As a rule, a GTD's (gas-turbine engine) exhaust gases are pure; however, in case of possible violations of the combustion cycles in the KS (compressor station) and operation on heavy liquid fuels deposits may appear on the heating surfaces. Therefore, in designing UT's it is necessary to provide for the possibility of their periodical cleaning (washing, shot-cleaning, and so forth).

For the reasons indicated above it is feasible to design steam generators operating on discharge gases in spiral-shaped forms with forced circulation in accordance with the type of utilization steam generators which are in widespread use in many branches of industry. Forced circulation allows us to position the drum-separator in any manner in relation to the spiral-shaped heating surfaces, to place one drum on the steam generators of several GTD's or on several sections of the steam generator of a high-capacity GTD.

Drum-separators with circulating and feed pumps, KIP (combined source of feeding), and automatic control may be positioned in a common enclosed area, while the spiral-shaped steam generators and network water-heaters may be placed in the open air, since they have no elements which require constant servicing or monitoring.

At a relatively small number of GTU's or at large-scale GTU's it is feasible to apportion the steam generators and network water-heaters to several parallel sections. In case one of the sections goes out of order, all the gases from the GTD may be passed through those remaining in operation, since the anti-pressure of the turbine may always be temporarily raised to the necessary limits with a certain reduction in the GTU's efficiency. The increase in the mass expenditure and velocity of the gases passing through the sections remaining in operation increase the heat-yield coefficient and the average temperature pressure in the UT, as a result of which the heat capacity of the operating sections increases. For example, during the switchover of one of the two sections the forced heating capacity of the operating section ordinarily amounts to about 80 percent of nominal (without sub-heating). The sectioning of UT's averts the necessity of having reserve heating surfaces.

The potential productivity of a steam generator (Figure 7-4) is determined by the following method. The economically justifying minimal temperature variation at the "cold" end of the vaporizer part of the steam generator is determined by the nomograph of Figure 7-5 and on the average is equal to $\Delta t_x = 30 \div 40^\circ$ C.

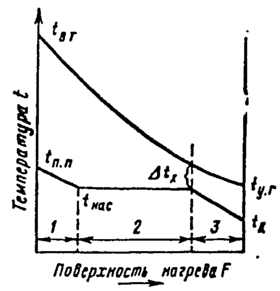

Figure 7-4 Schedule of Temperatures in a Steam Generator Operating on Exhaust Gases of a GTD

Key:

1. Steam Superheater
2. Vaporizing Part
3. Economizer

$t_{\text{в.т}}$ represents the temperature at the turbine's exhaust; $t_{\text{п.п}}$ -- temperature of the superheated steam; $t_{\text{нас}}$ --temperature for boiling water; t_x temperature of water from the deaerator; $t_{\text{у.г}}$ temperature of escaping gases; Δt_x --temperature variation at the "cold" end of the vaporizing surface

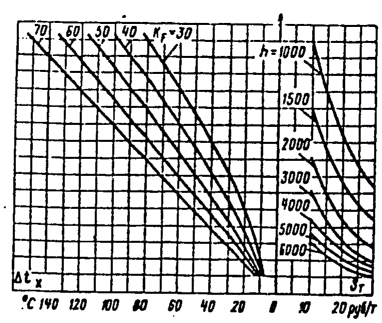

Figure 7-5 Nomograph for Determining Economically Justified Temperature for Undercooling Heating Gases in a Utilization Heat Exchanger

Key:

$s_т$ represents proportional expenditures on fuel, rubles per ton; h --number of hours utilizing installed heat capacity, hours per year; K_F --specific complete cost of heating surface, rubles per sq. meter; Δt_x --economically justified temperature of undercooling, °C. Nomograph constructed for a heat exchanger with a lateral flow of grid clusters of pipes 28 × 3 in diameter with a spacing in a row S_1 = 72 mm and a spacing for the movement of gases S_2 = 50 mm.

From the design of the heat schematic of a GTD we know the expenditure of exhaust gases $G_т$, their temperature $t_{в.т}$ and heat consumption c_p. The quantity of heat which may be given off by gas for vaporizing water and superheating steam in a steam generator (PG) is as follows:

$$Q_{пг} = c_p G_т (t_{в.т} - t_{нас} - \Delta t_x). \qquad (7\text{-}12)$$

The potential steam productivity by using a boiling economizer is[5]

$$D_{пг} = \frac{Q_{пг}}{i_{п.п} - \bar{i}_{нас}} \eta_{пг}, \qquad (7\text{-}13)$$

where $i_{п.п}$ represents the enthalpy (heat content) of the superheated steam; $\bar{i}_{нас}$ --the enthalpy of the water in a saturated state at $t_{нас}$; $\eta_{пг}$ -- the coefficient which accounts for the heat losses into the surrounding environment, usually equal to 0.98.

The economizer part of the steam generator does not yield a significant reduction in the temperature of the heating gases because of the large relationship $G_т/D_{пг}$, which is several times greater than in steam generators operating on fuel.

As a rule, consumers require hot water together with steam, and this allows us to cool down the escaping gases of a TGTU to an economically feasible limit, for example, to 100--120° C. The dimensions of a steam generator must be selected in accordance with the maximum steam load; hence, it is feasible to provide a buffer-type steam preheater of the network water (Figure 7-6) in which the periodical surpluses of steam may be utilized. This is more expedient than regulating the PG's productivity by means of a by-pass of part of the gas past it into the network-water preheater, since in the first instance the total area of the heating surface of the steam generator and the network-water preheater would be less. Furthermore, it is simpler to guarantee the maintenance of the required network-water temperature τ_1 in the heat-network feed line.

Calculating the area of the heating surface of a steam generator and a network preheater and determining their design dimensions are carried out in accordance with the normative method [63]. The optimum velocity of the gases is determined by the nomograph of Figure 7-7.

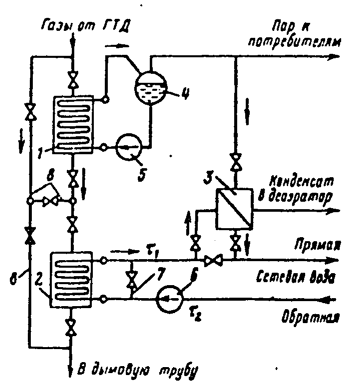

Figure 7-6 Switching Schematic of a Steam Generator and Network-Water Preheater, Operating on the Exhaust Gases of a GTU

Key:

1. Steam Generator
2. Network-Water Preheater
3. Steam Network-Water Preheater
4. Steam Generator Drum-Separator
5. Steam-Generator Circulating Pump
6. Network Pump
7. Regulating Seal
8. By-pass Gas Conduits

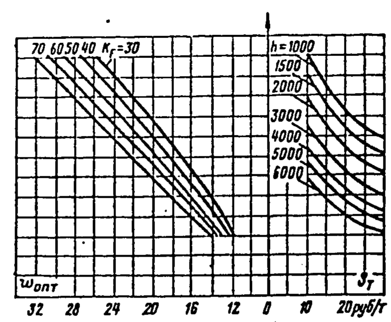

Figure 7-7 Nomograph for Determining Optimum Velocity of the Heating Gases in the Utilization Heat Exchanger of a GTU

Key:

$З_т$ represents proportional expenditures on fuel, rubles per ton; h --number of hours utilizing installed heat capacity, hours per year; k_F --specific complete cost of heating surface, rubles per sq. meter; $w_{опт}$--optimum gas velocity, meters per second. Nomograph constructed for a heat exchanger with a lateral flow of grid clusters of pipes 28 × 3 in diameter with a spacing in a row s_1 = 72 mm and a spacing for the movement of gases s_2 = 50 mm.

The resistance of heat exchangers operating on exhaust gases exerts a noticeable influence on the capacity of GTD's, and it must be taken into consideration in determining the optimum gas velocities in UT's and the choice of their design.

Reduction of the capacity of a GTD, brought about by an increase in gas-turbine counterpressure, is most simply and sufficiently accurately determined in the following manner. Increasing the counterpressure from $p_{в.т}$ to $p'_{в.т}$ decreases the operation of the gas in the turbine by $\Delta l_т$, with the area being measured of 1-6-5'-2-1 (Figure 7-8). The fall in the gas pressure in utilization heat exchangers $\Delta p_{у.т} = p'_{в.т} - p_{в.т}$ does not usually exceed 1000--3000 Pa (~ 100--300 mm water gage). Therefore, the area 1-6-5'-2-1 may with sufficient accuracy be considered equal to the area 1-6-5-2-1, which is equal to $\Delta p_{у.т} V_{в.т}$. The change in the volume of gases due to an increase in pressure by $\Delta p_{у.т}$ may be disregarded, as this is also done in calculating the capacity of smoke pumps and fans.

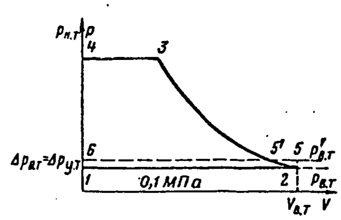

Figure 7-8 Influence of a Change in a Gas Turbine's Counterpressure on Its Capacity (Specific Operation)

A reduction in the capacity of a gas turbine and, consequently, that of a GTD on the whole as well, because of an increase of counterpressure by comprises the following, in kW:

$$\Delta N^{э}_{ГТУ} = \Delta p_{у.т} V_{в.т} \eta_т 10^{-3}, \quad (7\text{-}14)$$

where $\Delta p_{у.т}$ is expressed in Pascals; $V_{в.т}$ represents the volumetric expenditure of gas escaping from the turbine with the data $t_{в.т}$ and $p_{в.т}$, m^3/c; and $\eta_т$ is the turbine's relative efficiency.

An increase in the counterpressure to $p_{y.т} \leqslant$ 5000 Pa decreases the expenditure of the operating gas through the GTD by only a fraction of a percent, and, therefore, this factor may be disregarded. On an average the installation of a UT reduces the maximum potential capacity of a GTU by 1--1.5 percent. For a large part of the year, when the outdoor air temperature is lower than nominal for a given GTU (usually 16--20° C), the capacity of a GTU may be raised by raising the temperature of the gas before it enters the turbine all the way up to the nominal level (See §6-3). In this case the resistance of the UT brings about not of the capacity but of the efficiency of the GTU of approximately the same degree.

An example of the component make-up of a heating GTU is shown in Figure 7-9.

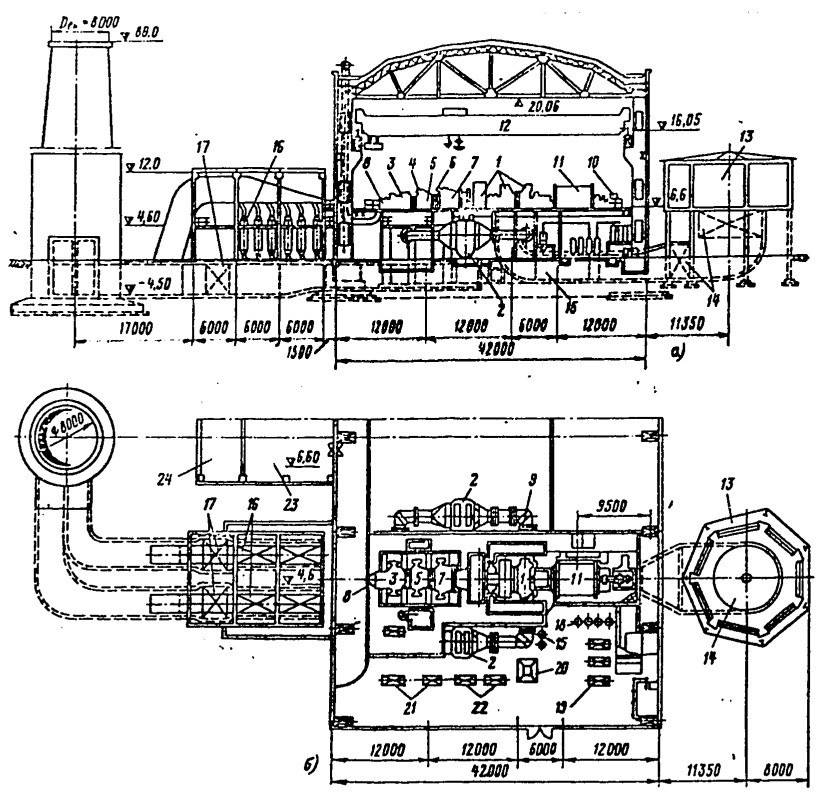

Figure 7-9 Example of the Component Make-Up of a Heating GTU

Key:

a Cross-Section
b Floor plan
1. Low-Pressure Compressor (KND) with a Capacity of 80 MW
2. Intermediate Air-Cooler
3. High-Pressure Compressor (KVD) with a Capacity of 110 MW
4. High-Pressure Combustion Chamber (KSVD)
5. High-Pressure Turbine (TVD) with a Capacity of 180 MW
6. Low-Pressure Combustion Chamber (KSND)
7. Low-Pressure Turbine (TND) with a Capacity of 180 MW
8. Start-Up Turbine
9. Compensators
10. Generator Excitor
11. TVF-100-2 Generator with a Capacity of 100 MW
12. Overhead Crane 125/20 t
13. Pumping Chamber
14. Noise Dampers
15. Regulating Oil Pump
16. Network-Water Preheaters
17. Place for Installing Dampers
18. Oil Coolers
19. Oil Pumps
20. Regulating System's Oil Tank
21. Circulating Pumps
22. Pumps of the Gas Coolers
23. Pumps
24. Area of the Control Bloc Panel

7-3 General Characteristics of Steam-Gas Units

Steam-gas units (PGU's) are created by combining steam-power units (PSU's) and gas-turbine units (GTU's). Such a combined unit attains a higher level of efficiency than those of the PSU and GTU of which it is comprised; moreover, a number of design advantages are attained which makes this unit less expensive.

The efficiency increase in combining the PTU and the GTU is attained as a result of thermodynamic topping of the steam cycle by a higher-temperature gas cycle, and also due to a reduction in the proportional losses of heat with the escaping gases.

Figure 7-10 shows the schematic of a PTU in which an efficiency is increased solely by means of topping the steam cycle with a gas one. The transfer of the produced heat of the gas cycle to the steam cycle is carried out by preheating and sometimes also by partially evaporating the steam generators' feedwater by mans of the GTU's exhaust gases. The expenditure of the escaping gases in the case of this PSU (12 and 15) is practically equal to the total expenditure of the escaping gases of a PTU and a GTU prior to their combination. But the temperature of the escaping gases of a GTU $t^{\text{пг}}_{\text{у.г}}$ is considerably lower than in a separate GTU and is approximately equal to the escaping gases of steam generators $t^{\text{пг}}_{\text{у.г}}$. The more profound utilization of the heat of a GTU's escaping gases is also a source of fuel savings.

The schematic of a PGU in which fuel savings are achieved by means of a considerable reduction in the proportional expenditure of escaping gases, is shown in Figure 7-11.

In this schematic there is no topping of the steam cycle by a gas cycle, since both cycles receive heat directly from the fuel in the steam generator. But the total proportional expenditure of the PGU's escaping gases is practically equal to the expenditure of gases by the GTU alone prior to its inclusion in a PGU. Accordingly, there would be declines in the losses of heat together with the escaping gases of a PSU, which it had prior to inclusion in the PGU. This is also a source of fuel savings in the case of the PGU schematic under consideration.

The potential for such a reduction in the proportional expenditure of escaping gases is explained by the fact that in the GTU's combustion chambers fuel is burned with a very great abundance of air $\alpha_{\text{к.с}} = 5 \div 8$ (See Chapter 6). Therefore, when a GTU is combined with a PSU, the amount of air which is fed into the combustion chamber (preheater) 3, which also serves as the steam generator's combustion chamber, is not increased, whereas the burning of additional fuel, the heat of which is passed into the steam cycle, occurs by means of the reduction $\alpha_{\text{к.с}}$.

When fuel is used having a large heat of combustion (liquid fuels, natural gas), the mass of additionally burned fuel comprises only a certain percentage of the mass expenditure of gases through the GTU. Therefore, the mass expenditure of a PGU's escaping gases only insignificantly exceeds the expenditure of a GTU's gases prior to the latter's inclusion in the PGU schematic.

A certain increase in the expenditure of the operating gas through the gas turbine increases its capacity, while the compressor's capacity remains unchanged, and this leads to a noticeable increase in the GTD's usable capacity (See Table 6-1).

If in the PGU according to Figure 7-11 the GTU's escaping gases are not to be discharged directly into the atmosphere but rather directed at heating the steam generators' feedwater, as in the schematic shown in Figure 7-10, then this will be carried out by topping the steam cycle with a gas cycle, and an additional appropriate fuel savings will be attained. In the PGU (Figure 7-12) a fuel savings is attained both by reducing the total proportional expenditure of escaping gases as well as by reducing the temperature of the GTU's escaping gases.

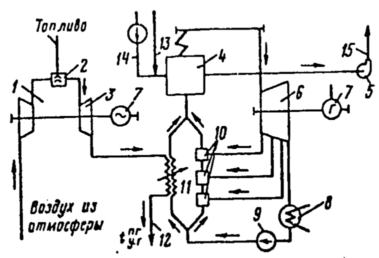

Figure 7-10. Schematic of a PGU Utilizing the Heat of a GTD's Gases to Heat Steam Generators' Feedwater

Key:

1. GTD compressor
2. Combustion chamber
3. Gas turbine
4. Steam generator
5. Flue-gas pump
6. Steam turbine
7. Electric generator
8. Condenser
9. Feed pump
10. Regenerative preheaters operating on bleeder steam
11. Gas preheater of feedwater
12. GTD gases into the atmosphere
13. Fuel into the steam generator
14. Air into the steam generator's combustion chamber
15. Steam generator's flue gases into the atmosphere

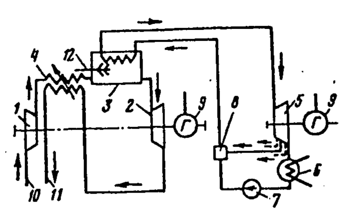

Figure 7-11. Schematic of a PGU without Topping a Cycle

Key:

1. GTD compressor
2. Gas turbine
3. High-pressure steam generator
4. GTD regenerator
5. Steam turbine
6. Condenser
7. Feed pump
8. Regenerative preheater of feedwater
9. Electric generator
10. Air from the atmosphere
11. Escaping gases
12. Fuel

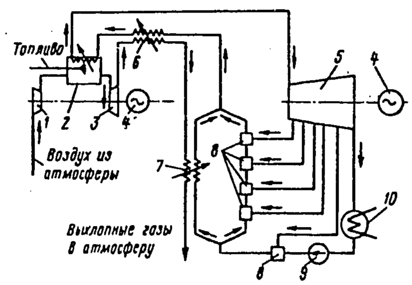

Figure 7-12. Schematic of a PGU with a High-Pressure Steam Generator

Key:

1. GTD compressor
2. High-pressure steam generator (VP)
3. Gas turbine
4. Electric generator
5. Steam turbine
6. Steam generator water economizer
7. Gas preheater of feedwater
8. Regenerative preheater of feedwater
9. Feed pump
10. Condenser

The fuel savings provided by the PGU (or, what amounts to the same thing, a relative increase in efficiency) must be determined by means of comparison with the efficiency of the best of the units included in the PGU in its individual operation rather than by comparing them with the average efficiency of units prior to their inclusion in a PGU.

At the present time the efficiency of the large-scale PSU's, as a rule, is higher than the efficiency of the GTU's; hence, the energy efficiency of the PGU's is determined by means of comparison with the efficiency of a PSU. In this case the steam parameters of the PSU are accepted as the same as in the steam part of the PGU. Accordingly, the hourly fuel savings provided by the PGU are equal to the following:

$$Q_{\text{эк}} = N_{\text{пгу}} (q_{\text{кэс}} - q_{\text{пгу}}), \quad (7\text{-}15)$$

where $N_{\text{пгу}}$ represents the capacity of the steam-gas unit, in kW; $q_{\text{кэс}}, q_{\text{пгу}}$ are the respective proportional fuel heat expenditures in steam-turbine and steam-gas units, in kJ/(kW-hrs).

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Examined below are a number of characteristics schematics for PGU's.

7-4 PGU's with High-Pressure Steam Generators

The operation of a PGU with a high-pressure steam generator (See Figure 7-12) proceeds in the following manner. The compressor compresses the air which is being taken in from the atmosphere and feeds it into the combustion apparatus of the high-pressure steam generator (VP)[6]. From the VP the products of combustion enter into the gas turbine, are expanded in it, and are directed to preheat the steam generator's feedwater, after which they are discharged into the atmosphere.

Steam of the VP expands in the turbine, condenses in the condenser, the condensate is preheated by the GTU's exhaust gases and partially by the turbine's bleeder steam, and enters into the VP. The quantity of fuel which may be burned in a VP is limited by the minimally allowable surplus of air during a combustion of $\alpha_{в.п} = 1.05 \div 1.20$. When the air surpluses are relatively modest, the combustion temperature considerably exceeds the level allowable before the gas turbine. Lowering it to the necessary level is achieved by drawing off heat to vaporize water and superheat steam in the VP.

The amount of heat which is transmitted to the steam section of the PGU exceeds several times over the amount of heat which is received by the gas part of the PGU ($\alpha_{в.п}$ and is several times less than $\alpha_{к.с}$).

Accordingly the capacity of the steam part $N_п$ of the PGU also acquires several times more capacity than the gas part $N_г$. The ratio $N_п/N_г$ depends on the schematics and parameters of the PGU's steam and gas parts. The correlation of the capacities also depends upon the final surplus of air in the VP. The more $\alpha_{в.п}$, the less $N_п/N_г$.

The escaping gases of a GTU may be deeply cooled by the feedwater only when they escape fully or partially from being superheated by the turbine's bleeder steam. The proportion of the remaining steam regenerative preheating depends on the correlation between the heat equivalents (systems' heat consumptions) c_pG, which heat the escaping gases and the feedwater. If this correlation is such that, in order to cool the escaping gases down to the optimum temperature in accordance with the economic indicators sufficient only for part of the feedwater, then it would be feasible to carry out the preheating schematic as shown in Figure 7-12. With this schematic the expenditure of water through the gas preheater is selected in such a way that the system's heat consumption and the waste-gas--water would be equal.

The equality of the heat consumptions ensures an equal diversity of temperatures along the entire heating surface of the heat exchanger which is selected as optimum in accordance with economic considerations. A minimal diversity of temperatures is achieved by a minimum of non-returnable losses caused by finite temperature differences.

Reducing steam regeneration by means of preheating part of the water by gas leads to a reduction in the output of electric power by the steam section in internal heat consumption. Therefore, the fuel heat savings in a PGU $Q_{эк}$ will be less than the amount of heat $\Delta Q_{у.г}$, transmitted by escaping gases to the feed water:

$$Q_{эк} = \sum (\xi \Delta Q_{у.г}), \qquad (7\text{-}16)$$

where ξ is the coefficient of the heat value of the corresponding bleeding.

In PGU's use may be made of GTU's not only in accordance with the simple schematic shown in Figure 7-12 but also following the schematic with intermediate cooling, preheating, and heat regeneration. The use of a GTU regenerator complicates the unit and makes it more expensive, and in the case of the PGU provides practically no fuel savings according to the schematic (See Figure 7-12). The latter is explained by the fact that when the regenerator is installed there is a corresponding reduction in the amount of heat received by the VP's feed water from the gases. Hence, non-regenerator-type GTU's are used for PGU's.

Nor, in most cases, does intermediate cooling of the compressor yield any fuel savings (if the heat of the cooling water is not used). Intermediate preheating in a GTU yields a substantial effect.

The higher the initial parameters of the steam-turbine unit, the less is the value coefficient of steam heat from bleedings, which are being fully or partially replaced by GTU produced gases; therefore, the higher the steam parameters, the less fuel savings provided by topping the steam cycle by a gas cycle [formula (7-16)] and the less the fuel savings obtained by means of reducing the proportional heat losses with escaping gases.

As a result, the higher the higher the steam parameters, the less the efficiency of a PGU surpasses the efficiency of a PSU. Thus, with steam parameters of 9.0 MPa, a temperature of 535° C, and all other conditions being equal, a PGU has approximately 7 percent less proportional fuel expenditure than a PSU. With 13.0 MPa and 565° C the difference in proportional expenditures amounts to only 4 percent, while at 24.0 MPa and 565° C it is about 2 percent. At steam parameters of 3.5 MPa and 435° C a PGU yields a fuel savings of up to 20--25 percent. This does not mean that a PGU must be constructed with low steam parameters. The absolute efficiency of a PGU increases proportionately with the parameters of the steam component (provided that gas component has been correctly chosen). Therefore, the highest possible steam parameters should be adopted.

In a high-pressure steam generator the gases are under a pressure which is equal to the pressure before a gas turbine. Therefore, both combust and heat yield occur in it considerably more intensively than is the case in ordinary steam generators. As a result, the sizes and proportional expenditure of metal in VP's is several times less than in ordinary steam generators. Because of their small size VP's may be placed in a power house (Figure 7-13).

In connection with the advantages of a VP before the ordinary steam generators, as noted above, the cost of an installed unit of a PGU's capacity in serial equipment production may be 10--20 percent lower than the proportional cost of a PSU. A shortcoming of a PGU with a VP is the fact that it can operate only on fuel suitable for gas turbines.

Several PGU's with VP's are operating in the USSR. The first PGU with a capacity of 30 MW had in its operation an efficiency of 31.5 percent with steam parameters of 3.5 MPa and a temperature of 435° C. It is expected that the unit's efficiency may reach approximately 35 percent.

In 1973 a PGU with a capacity of 200 MW was put into operation at the Nevinnomyskaya GRES with a planned efficiency of as much as 37 percent at steam parameters of 13.0 MPa and a temperature of 540/540° C (Figure 7-13).

7-5. A PGU with an Ordinary Steam Generator

The exhaust gases of a GTU contain 15--18 percent of oxygen (See Chapter 6). This allows them to be used for burning fuel in the combustion chambers of ordinary steam generators (Figure 7-14). Moreover, the physical heat of the GTD's exhaust gases is fed into the combustion chamber and utilized. Such units are called PGU's with a discharge of gases into the steam generator. And in this case the steam generator may not have an air-preheater, and the escaping gases may be cooled only by the feed water. So that the feed water may be deeply cooled by the escaping gases, it is necessary, as in the schematic shown in Figure 7-12, to reduce or completely exclude the steam regeneration.

With regard to the schematic under consideration the PGU's efficiency is approximately the same as in the schematic with a high-pressure steam generator with similar gas-turbine and steam-turbine units. This is explained by the fact that the proportional expenditure of escaping gases in both schematics is practically identical, and their temperatures are also similar. The degree of steam regeneration displacement is likewise approximately the same. Some variation in efficiency is caused by the fact that in the schematic with the high-pressure steam generator the mass expenditure of gas through the turbine along with an equal supplying of air by the GTD compressor is several percentage points more than in the schematic with an ordinary steam generator; this is owing to the fact that in the VP all the fuel expended by the PGU is burned, while in the case of a PGU with an ordinary steam generator only part of this fuel is burned. The large gas expenditure is accompanied by a greater capacity of the gas turbine (all other conditions being equal), and, consequently, by the PGU's efficiency as well (See Table 6-1).

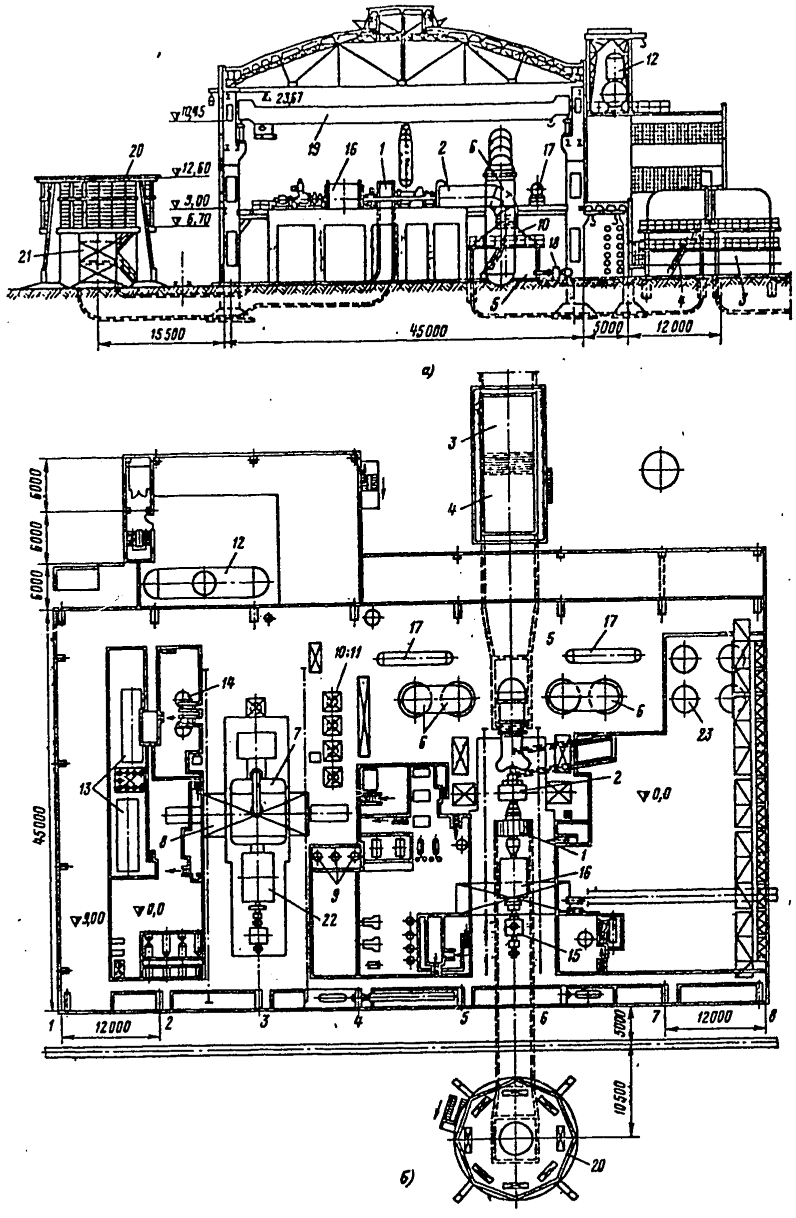

Figure 7-13. Composite 200 MW (PGU-200) Steam-Gas Unit at the Nevinnomysskaya GRES

Key:

a. Cross-section
b. Floor plan
1. Compressor
2. Gas turbine
3. Third-degree economizer
4. Second-degree economizer
5. First-degree economizer
6. VPG-450 high-pressure steam generator
7. K-160-130 steam turbine
8. Condenser
9. Condenser pump
10. and 11. Low-pressure preheaters
12. Deaerator
13. Feedwater pump
14. High-pressure preheater
15. Start-up steam turbine
16. TVF-60-2 generator
17. Drum separator
18. Steam generator circulating pumps
19. Overhead crane with a hoisting capacity of 125/20 tons
20. Pumping chamber with filters
21. Noise dampers

In the case of PGU's with an ordinary steam generator, as well as in PGU's with a VPG, the introduction of intermediate preheating in the GTD increases the entire unit's efficiency. The effect of steam parameters on PGU efficiency in accordance with the schematic under consideration is the same as in the case of the schematic with a high-pressure steam generator (See Figure 7-12). Also approximately the same in both schematics is the relationship of the capacities of the steam and gas components N_n/N_r.

The principal merits of the PGU with an ordinary steam generator are as follows:

1) the possibility of operating the steam generator on any fuel; moreover, 70--80 percent of the unit's total fuel expenditure is burned in the steam generator;

2) the possibility of using ordinary steam generators with appropriate remakes of the tail sections and also for certain elements of the combustion-chamber apparatus and the steam reheater; this facilitates the creation of a PGU, based on serial equipment, and it allows us to carry out the gas-turbine topping of existing steam-turbine electric-power stations with the installed equipment being maintained;

3) the possibility of both joint and individual operation of the steam and gas components of the units, while maintaining the flue-gas pumps and fans.

The surplus of air in the steam generator within the limits of $\alpha \leqslant 2$ has comparitively little influence on the efficiency of a PGU, and this facilitates the selection of serial GTD's and steam generators.

In the case of the steam generators we must develop a water economizer which, together with a gas preheater for the feed water (Figure 7-14, Nos.

7--8), is positioned in the place which was formerly occupied by a water-cooler. In the United States PGU's with ordinary steam generators in many instances retain flue-gas pumps and fans. This allows the steam component to operate within the installed gas component.

In the PGU schematic under consideration (See Figure 7-14) the GTD's regenerator may be installed before or after the steam generator. In both instances, as is also true in the case of the PGU witha VPG, this regenerator yields practically no fuel savings, since it leads only to a redistribution of the fuel expenditure among the GTD and the steam generator within its same total expenditure. However, thanks to this redistribution, the GTU regenerator unit reduces the requirement for gas-turbine fuel, and it is replaced by boiler fuel, which is cheaper in many cases. Therefore, in PGU's with ordinary steam generators the installation of GTD regenerators may turn out to be feasible.

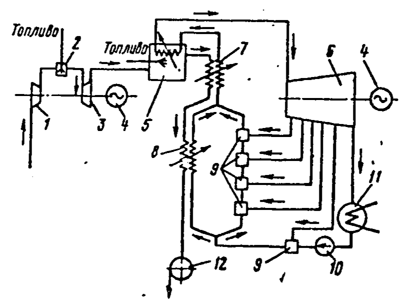

Figure 7-14. Schematic of a PGU with an Ordinary-Type Steam Generator

Key:

1. GTD compressor
2. GTD combustion chamber
3. Gas turbine
4. Electric generator
5. Ordinary-type steam generartor (under blower or with a flue-gas pump)
6. Steam turbine
7. Water economizer of the steam generator
8. Gas preheater of feed water
9. Steam regenerative preheaters
10. Feed pump
11. Condenser
12. Flue-gas pump

In building new electric power stations to be equipped with PGU's with ordinary steam generators, capital outlays should be greater than in the case of PGU's with high-pressure steam generators, since the cost of the latter in serial production should be lower than the cost of ordinary steam generators and requires less space. Abroad most PGU's are constructed according to a schematic with ordinary steam generators.

7-6. PGU's with Complete Topping of the Cycle

In the PGU schematic with complete topping (Figure 7-15) the steam generator is heated solely by the GTD's escaping gases; accordingly, in the given type of PGU there is complete topping of the steam cycle by the gas cycle.

Such units are designated as PGU's with a discharge of gases into the utilization steam generator, as well as gas-steam units.

In the PGU's examined earlier the steam part received the principal part of the heat directly from fuel and only a relatively small part of the heat from the GTD's exhaust gases; accordingly, in these schematics there is a partial topping of the cycles.

The temperature of the exhaust gases of non-regenerator GTD's usually does not exceed 350--550° C, while that of the regenerator GTD's usually does not exceed 270--320° C. At such temperatures of the heating gases the steam pressure (boiling temperature, see Figure 7-4) exerts a very great influence on the potential productivity of the steam generator $D_{\text{ут}}$. The higher the steam pressure, the less of it is produced by the steam generator, but the work capacity of each kilogram of steam will be greater ($l_{\text{т}} = \Delta i_{\text{т}}$). In connection with this, there is an optimum steam pressure at which the process $D_{\text{ут}}\Delta i_{\text{т}} = N_{\text{т}}$ reaches a maximum.

Figure 7-16 shows the dependence of the proportional (relative) capacity of steam turbine $\bar{N}_{\text{п}}$ /See Formula (7-17)/ from the accepted pressure in the steam generator, designed for a GTU with a temperature of the escaping gases of $t_{\text{у.г}}$ = 390° C and g = 24 kg/(kW-hrs). As may be seen from the drawing, the maximum capacity of a PGU is attained at relatively modest steam pressures

$$\bar{N}_{\text{п}} = N_{\text{п}}/N_{\text{г}}. \qquad (7\text{-}17)$$

In the PGU schematic under consideration the production of electric power by the steam component occurs without an additional fuel outlay (if we disregard capacity losses of 1--2 percent, caused by the steam generator's resistance to the passage of exhaust gases); therefore, the PGU's efficiency is equal to the following:

$$\eta_{\text{пгу}} = \eta_{\text{гту}} (1 + \bar{N}_{\text{п}}). \qquad (7\text{-}18)$$

Thus, the efficiency of the PGU in accordance with the schematic under consideration depends on the efficiency of the GTU $\eta_{\text{гту}}$ entering into it and the proportional capacity of the steam component $\bar{N}_{\text{п}}$. If $\eta_{\text{гту}}$ = 25 percent and $\bar{N}_{\text{п}}$ = 0.3 (Figure 7-16), then the PGU's efficiency amounts to $\eta_{\text{пгу}}$ = 25 (1 + 0.3) = 32.5 percent. When $\eta_{\text{гту}}$ = 30 percent and $\bar{N}_{\text{п}}$ is the same, the efficiency of the PGU $\eta_{\text{пгу}}$ = 30 (1 + 0.3) = 39 percent.

At a high temperature of the escaping gases $t_{y.r} = 500 \div 550^{\circ}$ C in the new high-temperature GTU's the optimum steam pressure rises, and there is an increase in the proportional (relative) capacity of the PGU's steam component and its efficiency.

In the United States PGU's are manufactured in accordance with the described schematic with a capacity ranging from 50 to 250 MW and with steam parameters of 8.5 MPa, 510° C; their efficiency reaches 40 percent [41]. In such PGU's, similar to the cases of heating GTU's, use is made of complete or partial sub-heating of the steam generators. As was shown in § 7-2, the fuel heat which is expended on the sub-heating is utilized with a high degree of efficiency, since there is practically no increase in the expenditure of escaping gases. Sub-heating considerably increases the optimum steam pressure and thereby the efficiency of using the heat from a GTU's escaping gases.

Constructing PGU's in accordance with Figure 7-15 with low steam parameters may be economically advantageous if the GTU is installed regardless of whether or not it will have a tail steam-power component. The foregoing relates to GTU's being used to drive production machines, turbocompressors, at industrial enterprises, injection pumps at the compressor stations of main pipelines, and so forth.

In this case the economic feasibility of creating a PGU, based on a GTU, should be determined by taking into consideration only the following additional outlays connected with this: the cost of the steam-power component and the equipment connected with it.

A steam turbine may be installed either on the shaft of a GTD or separately. In the first case it is utilized to drive that same machine, in the second case--to drive a separate machine, or to produce electric power; here the turbine may receive steam from several GTU's. The steam which is received in the steam generator may be used not only in the steam turbine but also in the gas turbine, as is shown by the dotted line in Figure 7-15. In this case there is no further need for a steam-turbine unit and the structures connected with it (the system of circulating water supply, etc.).

The feeding of steam into the combustion chamber increases the expenditure of the operating element through the turbine $G_{т}$, and consequently, the pressure as well $p_{н.т}$ [See Formula (6-16)]. Due to the increase $p_{н.т} \approx p_{н.к}$ there is a decrease in the expenditure of air through the compressor (along line n = const, Figure 6-9), and its operational point approaches the pumpage line. Hence, the amount of steam which may be fed into the combustion chamber is limited by the conditions of stable operation by the compressor. The expenditure of steam may also be limited by the strength of the turbine aggregate's elements.

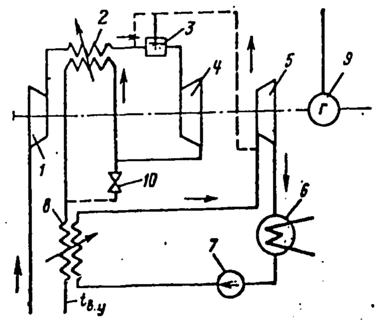

Figure 7-15. Schematic of PGU with Complete Topping of Cycle

Key:

1. Compressor
2. GTD regenerator
3. Combustion chamber
4. Gas turbine
5. Steam turbine
6. Condenser
7. Feed pump
8. Steam generator operating on GTD exhaust gases
9. Electric generator
10. Regenerator by-pass

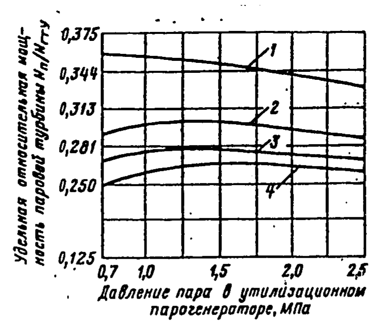

Figure 7-16. Dependence of Steam-turbine Capacity on Steam Pressure in Steam Generator Operating on GTD Exhaust Gases. Temperature of Exhaust Gases 395° C. Steam Before the Turbine--Saturated.

Key:

1. Steam pressure in condenser at 5 kPa
2. 20 kPa
3. 30 kPa
4. 50 kPa

The expenditure of steam from a utilization steam generator (UP) is 10--20 times less the expenditure of gas through a GTD; therefore, practically all the steam from a UP may usually be fed into the combustion chamber.

The degree of steam expansion in the gas turbine is many times less than in a steam turbine with a condenser, but in the first instance the superheating of steam is much higher: 700--800 °C. As a result, the work of one kg of steam in steam and gas turbines comes out approximately the same (equal). Thus, at an initial steam pressure of 0.6 MPa, a pressure in the condenser of 8 kPa, and a temperature in front of the gas turbine of 800° C the work of one kg of steam in a gas turbine is practically the same as in a steam turbine.

Fuel heat amounting to about 7500 kJ/(kW-hrs) is expended additionally to superheat steam in the combustion chamber. The corresponding proportional expenditure of fuel [about 260 grams/(kW-hrs)] is 30--40 percent less than the average for up-to-date rayon KES's. The use of steam in a gas turbine may be especially economical in those cases where the steam generator, operating on escaping gases, is built not specially for this unit but to receive steam yielded to production.

Moreover, in a gas turbine use is made of periodic steam surpluses, for example, in nightime and non-working periods, seasonal surpluses, etc., but constant small surpluses of steam are also possible. Use may likewise be made in GTU's of steam surpluses from other utilization units present in the plant (systems of vaporization cooling of technological aggregates, and the like). Use in the GTD of periodic steam surpluses does not bring about supplementary capital outlays for a steam generator. Hence, the production cost of additional electric power produced by steam is determined only by the comparitively modest proportional expenditure of fuel [about 260 grams/(kW-hr)], the cost of feedwater (which is completely lost), as well as outlays on outfitting the combustion chamber to superheat steam, on an automated system, etc. Thanks to such small outlays, we can obtain electric power produced by additional steam cheaply.

7.7 Heating PGU's

A heating PGU includes a steam turbine with a steam bleeder or a counterpressure (Figure 7-17). Let's examine what fuel savings can be provided by a heating PGU in comparison with a steam-turbine TETs under stable, equal conditions (identical steam turbines, heat loads, etc.). In steam-turbine TETS's fuel savings are determined by the following formula (Chapter 2):

$$B^{\text{п}}_{\text{эк}} = Э^{\text{т}}_{\text{п. тэц}}(b_{\text{кэс}} - b^{\text{эт}}_{\text{п. тэц}}) - Э^{\text{к}}_{\text{п. тэц}}(b^{\text{э. к}}_{\text{п. тэц}} - b_{\text{кэс}}). \quad (7\text{-}19)$$

Inasmuch as in steam-gas units the heat of GTD exhaust gases is given off to the steam cycle, we can provisionally consider (by a methodological device) that a GTD which is included within a PGU produces all the electric power by a combined method on internal heat consumption with a proportional expenditure of $b^{эт}_{ГТУ}$.

Taking into account the combined production of electric power by the GTU, the PGU's fuel savings (under the same operating schedule) are as follows:

$$B^{ПГУ}_{эк} = Э^{т}_{ПТУ}\,(b_{КЭС} - b^{э.т}_{ПТУ}) + Э^{т}_{ГТУ}\,(b_{КЭС} - b^{э.т}_{ГТУ}) - Э^{к}_{ПТУ}\,(b^{э.к}_{ПТУ} - b_{КЭС}). \quad (7\text{-}20)$$

The second term of the equation (7-20) has a plus sign and provides a significant increase, since the dimension $Э^{т}_{ГТУ}$ usually comprises more than 20 percent of electric-power production by the PGU's steam component. The numerical values of the proportional fuel expenditures in the formulas (7-19) and (7-20) are diverse. Thus, if all the losses from escaping gases are attributed to the GTU (which simplifies the calculations), then the values $b^{э.т}_{ПТУ}$ and $b^{э.к}_{ПТУ}$ in the formula (7-20) must be determined without taking into account the heat which is carried off by the escaping gases, whereas by using the calculations in formula (7-19) they are determined with consideration being given to the efficiency of the TETs's steam generators.

Also different in the PGU's will be the combined production of electric power by the steam component $Э^{т}_{ПТУ}$ due to the decrease in steam regeneration. There are likewise corresponding changes in the condensation production $Э^{к}_{ПТУ}$.

It should be noted that because of the decrease in steam regeneration, as well as changes in the proportional expenditure of escaping gases and their optimum temperature, the fuel savings provided by a steam-gas TETs will not be proportional to the increase in the electrical capacity of a PGU as compared with a PSU $(N_п + N_г)/N_п$, despite the fact that the release of heat to outside consumers will remain in the case of the PGU's the same as it was in a single PSU which was included within a PGU,--the fuel savings will increase more slowly. The numerical value $b^{э.т}_{ГТУ}$ is determined from the heat balance of the PGU's gas-turbine balance

$$Q^{ГТУ}_{топ} = N_{ГТУ}/\eta_{эм} + Q_{пвр} + Q_{у.г} + Q_{о.в}, \quad (7\text{-}21)$$

where $Q^{ГТУ}_{топ}$ represents the fuel heat expended to heat up the gases before the turbine in the combustion chamber or VP; $Q_{пвр}$ is the heat given off to the feedwater in the gas preheaters; $Q_{у.г}$ is the heat carried off by the escaping gases after the gas feedwater preheaters of the PGU steam generators; $Q_{о.в}$ is the heat carried off by the water which cools off the gas in the GTU compressors (if there is a PO).

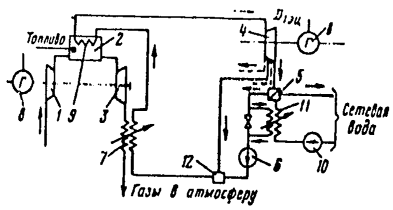

Figure 7-17. Schematic of a Heating PGU

Key:

1. Compressor
2. High-pressure steam generator
3. Gas turbine
4. Steam turbine
5. Network water preheater
6. Feed pump
7. Economizer
8. Electric generator
9. Heating surface of high-pressure steam generator
10. Network pump
11. Condensate cooler
12. Regenerative preheaters

As a rule, intermediate cooling of compressors is not utilized in PGU's; accordingly, the heat balance of a GTU within a PGU per kW-hr amounts to the following:

$$q_{\text{топ}}^{\text{ГТУ}} = 1/\eta_{\text{ГТУ}} = 1/\eta_{\text{эм}} + q_{\text{пвр}} + g c_p (t_{\text{у.г}} - t_{\text{н.в}}), \quad (7\text{-}22)$$

where $q_{\text{топ}}^{\text{ГТУ}}$ and $\eta_{\text{ГТУ}}$ represent the proportional expenditure of heat per kW-hr of a given GTU and its efficiency during independent operation; $q_{\text{пвр}}$ is the heat given off to the feedwater of the steam generator (preheater 7 in Figure 7-12);

$$q_{\text{пвр}} = c_p g (t_{\text{в.т}} - t_{\text{у.г}}), \quad (7\text{-}23)$$

$t_{\text{в.т}}$ represents the gas temperature at the turbine's exhaust; g is the proportional expenditure of the GTU's operating element (See Chapter 6); c_p is the proportional heat consumption of the escaping gases; $t_{\text{у.г}}$ is the temperature of the escaping gases after the gas feedwater preheater; $t_{\text{н.в}}$ is the temperature of the outside air, from which the unit's heat balance is drawn up.

For each specific GTU the numerical values $q_{\text{топ}}^{\text{ГТУ}}$, $\eta_{\text{ГТУ}}$, g, $N_{\text{ГТУ}}$, and $\eta_{\text{эм}}$ are known. The value of $t_{\text{у.г}}$ is determined by the adopted PGU schematic (the degree of change in steam regeneration).

From the equation (7-22) it follows that the proportional expenditure of fuel heat $q^{э.т}_{ГТУ}$ of a GTU which is included within a PTU per unit of electric power produced is equal to:

$$q^{э.т}_{ГТУ} = 1/\eta_{эм} + gc_p(t_{у.г} - t_{н.в}). \quad (7\text{-}24)$$

A GTU operates on full capacity during the operation of its steam component on the heating as well as on the condensation cycle; moreover, in the first approximation we may consider that the proportional fuel expenditure $b^{э.т}_{ГТУ}$ will be the same in both instances. This is explained by the fact that, although in the heating cycle the expenditure of feedwater is even more than in the condensation cycle, the temperature of the feedwater entering the preheater is, nevertheless, higher. As a result, there is little change in the heat transmitted by exhaust gases to the feedwater, $q_{пэр}$.

As research has shown, steam-gas TETs's may yield substantial additional fuel savings as compared with steam-turbine stations (with identical steam components). As a rule, the cost of a rated single kW at steam-gas TETs's is lower than at a steam-turbine TETs; hence, steam-gas TETs's may even be economical in those instances where steam-turbine TETs's are unjustified economically.

We have examined above the principal, characteristic schematics of PGU's, which may understandably have various modifications. More complex schematics are also possible, which combine the examined schematics or their individual elements. These schemes do not yield any substantial increase in fuel savings as compared with the PGU schematics already considered, and they have not been disseminated. Nor have PGU's been so far disseminated with turbines operating on a steam-gas mix, in which water is introduced directly into the combustion chamber [48]. The efficiency of such PGU's is lower than that of PGU's with a high-pressure steam generator and PGU's with ordinary steam generators. The advantage of such PGU's is the absence of steam turbines, condensers, etc.

Steam-gas units with only a partial topping (See Figure 7-10) yield considerably less fuel savings in comparison with other PGU schematics, but they are used quite extensively abroad because of their simplicity and their lack of need for special types of equipment.

In the USSR the PGU-200 steam-gas unit has been commissioned in accordance with a schematic with a high-pressure steam generator (See Figure 7-12) with a capacity of 200 MW. The composite make-up of this unit is shown in Figure 7-13.

In addition to the cases described in the previous paragraphs (GTETs's, mobile electric power plants, and others), the GTU finds a whole series of other applications at electric-power stations. Thus, at many TES's in Britain GTU's are utilized for reserves in supplying their own needs.

GTU's designed to cover peak electric-power loads have become very widespread. As is known, in order to cover peak electric-power loads, whose total annual duration amounts to 500--1500 hours, it is best to have suitable aggregates with the lowest possible initial cost at an acceptable level of efficiency and allowing a quick start-up. Peak-type GTU's satisfy these requirements quite well.

In most instances with regard to economic considerations it is feasible to install peak-type GTU's not individually but within steam-turbine TES's. Herein the following advantages are manifested. When the regenerative bleeders are switched off, the electrical capacity of the steam turbine may be increased by 10 percent and more (if this is permitted by the turbine's design). During the time when the steam bleeders are switched off the feedwater of the steam-turbine unit may be heated up to the same temperature by the exhaust gases of peak-type GTU's which have been installed at KES's. At the moment of electric-power peak load, when the GTU is started up and the steam regenerative preheaters are switched off, the total capacity of the TES may be increased significantly.

In addition to the station's great capacity increase, a further merit of the schematic under consideration is the electric-power station's economical operation during the peak operational cycle. In fact, during the GTU's operation and the PTU's feedwater heating by exhaust gases (peak schedule) the unit under consideration is similar to the PGU in accordance with Figure 7-10.

Table 7-1 cites the principal characteristics of present-day Soviet permanently installed GTU's.

FOOTNOTES

1. When the parameters of the released heat are increased, the fuel savings are decreased by 1--2 percent because of the increased pressure drop of exhaust gases in the utilization heat exchanger.

2. The coefficient of surplus air in these gases amounts to the following:

   $\alpha = 4 \div 7$ (See Chapter 6).

3. These values $\eta^{э}_{ГТУ}$ and g correspond approximately to the planned indicators of the GT-100-750-2 LMZ-type GTU with $\bar{t}_{н.в} = -5\,^{\circ}C$.

4. Depending on the efficiency of the ..oiler-type TETs, the expenditure on its own needs, and other factors.

5. When an economizer is lacking in the formula (7-13), instead of $\bar{i}_{нэс}$ we must substitute an enthalpy (heat content) for the feedwater of $\bar{i}_{п.в}$.

6. The steam generator is designated as high-pressure because of the high pressure of the combustion products within it.

Table 7-1. Principal Characteristics of Certain Soviet Permanently Installed GTU's

Type of GTU and Plant Manufacturing It	Nominal Capacity (in MW)	Efficiency of GTU (in percentages)	Temperature before Turbine (Nominal) (in °C)	Pressure Ratio in Compressor
GTK-10 (NZL) (Drive)	10	28.6	780	4.6
GTN-16 (TMZ) (Drive)	16	29.0	900	11.5
GTN-25 (NZL) (Drive)	25	29.4	850	12
GT-40 (NZL) (Drive)	40	30.6	950	15
GT-45 (KhTGZ) (Generator)	48	26.0	900	8.2
GT-100-750 (LMZ)	100	28.5	750	26.5
GT-100-750-M (Generator)	110	29.0	750	--
GT-150 (LMZ) (Generator Peak)	150	31.5	1050	14.7

Note. Values $q_{эк}$ and $Q_{т.м}$ are determined when $b_{КЭС}$ = 340 г/(кВт·ч); $\eta^{н}_{кот}$ = 0.88; $t_{у.г}$ = 110 °C.

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Table 7-1 (Continued)

Expenditure of Operating Gas (in G, kg/c / kg/kW-hrs)	Proportional Fuel Savings TГТУ at Full Heat Load	Potential Heat Release (in Gcal/hrs)	Proportional Cost of GTU in Volume of Plant Supply (in Rubles/kW)
86/30.9	0.70	13.6	42.9
81/18.2	0.78	25.5	---
175/25.2	0.76	35.0	39.6
209/18.7	0.86	56.0	30.0
268/20.1	0.69	80.0	---
448/16.1	0.78--	160--	45.2
---	0.72	120	---
630/18.2	0.87	220	About 25 (Preliminary)

Table 7-1 (Continued)

Notes
Two-shaft with regenerator without PO and PP. Serially manufactured
Two-shaft in accordance with simple schematic. Serially manufactured
Three-shaft without PO and PP. Pilot model GTN-25 in 1978. Can have generator modification
One shaft in simple cycle. In manufacture
Two-shaft with PO and PP. In manufacture
One shaft in simple cycle. Pilot model in 1980

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ELECTRIC POWER

KISELEV CELEBRATES 90TH ANNIVERSARY

Moscow GIDROTEKHNICHESKOYE STROITEL'STVO in Russian No 5, May 80 p 56

/ Article: "90th Anniversary of Petr Grigor'yevich Kiselev" /

/ Text / On 5 June 1980 will be completed 90 years from the birthday and 65 years of working activity of professor Petr Grigor'yevich Kiselev of the Moscow Engineering and Construction Institute imeni V. V. Kuybyshev.

Petr Grigor'yevich Kiselev is widely known as a scientific researcher and teacher in the field of hydraulics and hydraulic engineering.

He began his working career in 1915 after graduating from the Donetskiy Polytechnical Institute as an engineer on research and planning for irrigation of the transVolga country in Saratov. Then followed years of continuous work on the construction of hydraulic engineering projects, in planning and research and scientific research organizations. P. G. Kiselev began teaching in 1917 in the Polytechnical Institute in Rostov-na-Donu. Beginning in 1932 Petr Grigor'yevich taught in the Moscow Engineering and Construction Institute imeni V. V. Kuybyshev and was a member of the methodology commission of USSR MV and SSO / expansion unknown / and the specialized scientific council on the faculty of hydraulic engineering construction.

Professor P. G. Kiselev is a highly-qualified specialist in training engineering personnel; his textbooks are studied by the students of many institutes.

The textbook "Hydraulics and Aerodynamics" (co-authored) has been republished. "Reference Guide to Hydraulic Designs" under his editorship is used widely in planning organizations and, at present, has been published five times in the USSR and translated into Rumanian, Vietnamese and Chinese. This year the second edition of his study guide "Hydraulics (Fundamentals of Fluid Mechanics)" will be published.

Now Petr Grigor'yevich continues to work with unquenchable energy as a professor and consultant.

The long and fruitful work of professor P. G. Kiselev has been marked by government prizes -- the Order of Lenin and five medals.

Observing the 90th anniversary of Petr Grigor'yevich Kiselev, scientific society, his students and colleagues and the editorial staff of the magazine GIDROTEKHNICHESKOYE STROITEL'STVO with deep esteem congratulate him on a glorious jubilee and from all the heart wish him good health and further successes in his fruitful activity.

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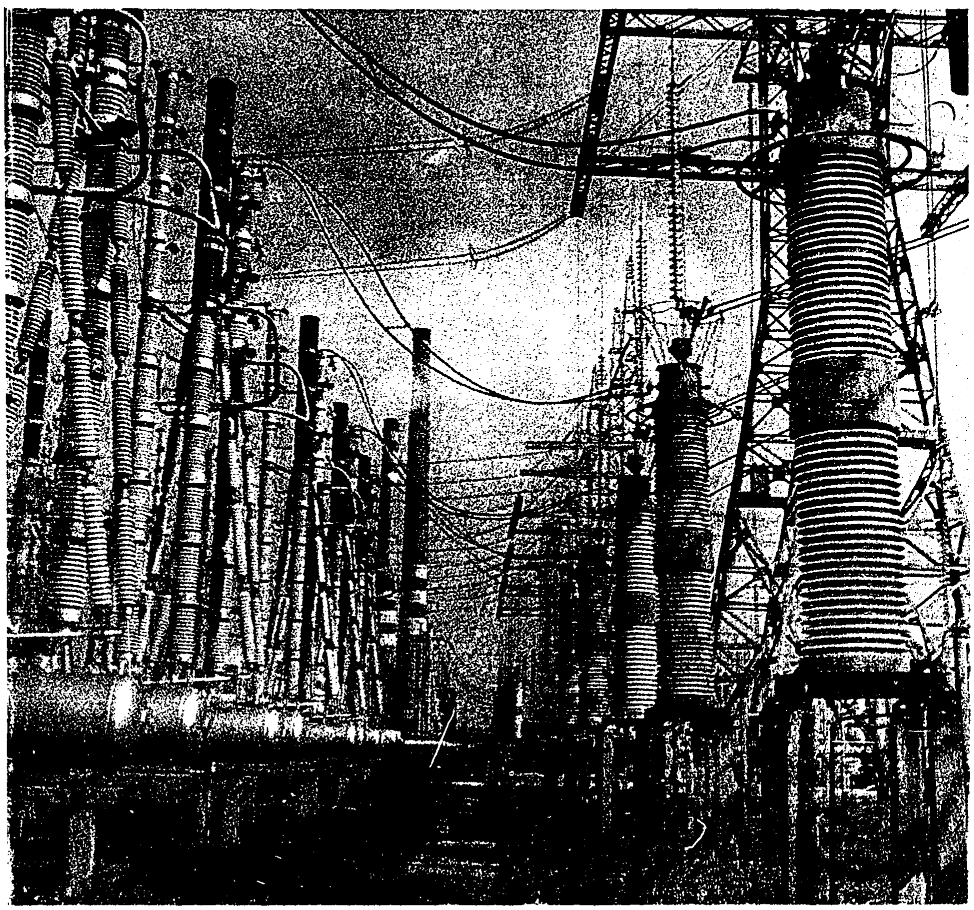
ELECTRIC POWER

HIGH VOLTAGE LINES

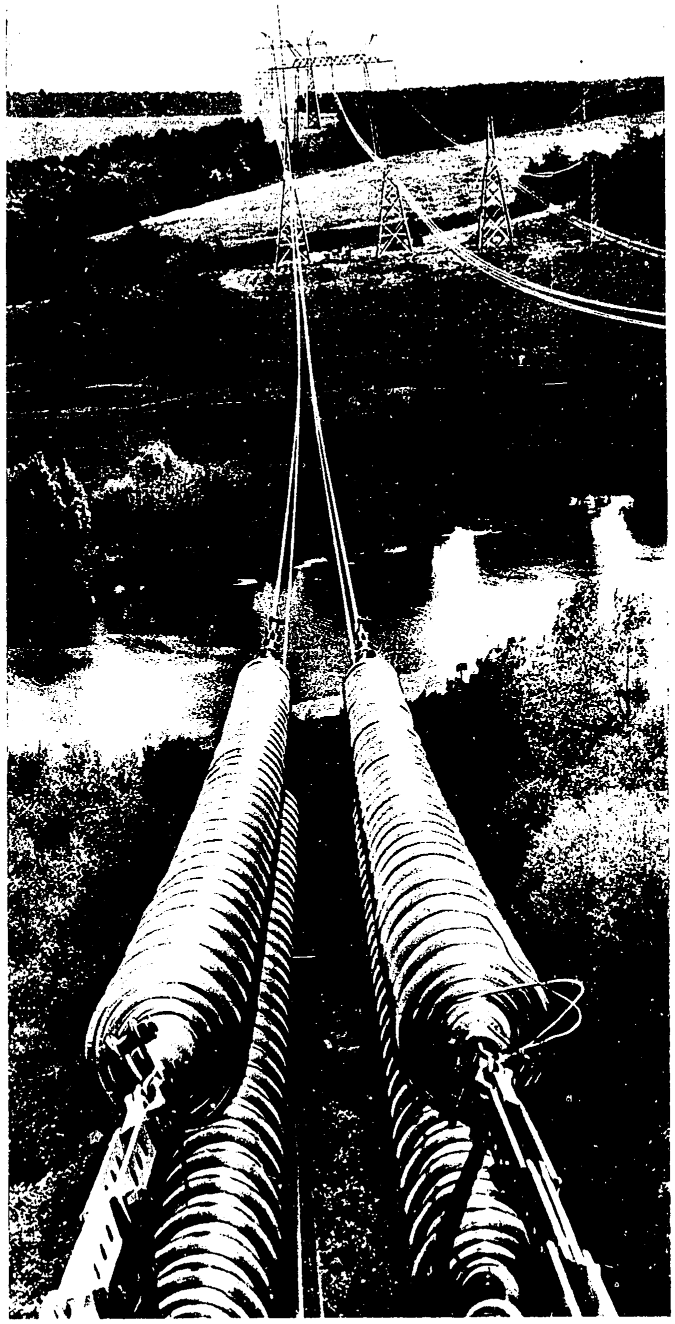
Moscow ENERGETIC in Russian No 6, Jun 80 front cover, inside front cover

[Photos and captions]

[Text]



330 kv Open Distributor



750 kv high-voltage line Donbass-West Ukraine

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END